PROCEEDINGS -

RENDEZVOUS AND PROXIMITY OPERATIONS WORKSHOP

HOSTED BY

NASA LYNDON B. JOHNSON SPACE CENTER
NASSAU BAY HILTON HOTEL
HOUSTON, TEXAS
19 - 22 FEBRUARY 1985

VOLUME II - PRESENTATIONS FROM SESSIONS 1 THROUGH 5A

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WORKSHOP ORGANIZER

27 MARCH 1985

VOLUME II - PRESENTATIONS FROM SESSIONS 1 THROUGH 5A

Due to the large quantity of information contained in the eleven sessions of the Rendezvous and Proximity Operations Workshop, the presentation material has been assembled into three volumes for the Proceedings. These three volumes (Volumes II - IV) are in addition to the Executive Summary (Volume I), which was published and distributed on 27 February 1985.

- Volume I - EXECUTIVE SUMMARY, 27 February 1985
- Volume II - PRESENTATIONS FROM SESSIONS 1 THROUGH 5A
- VOLUME III - PRESENTATIONS FROM SESSIONS 5B THROUGH 8
- VOLUME IV - PRESENTATIONS FROM SESSION 9 THROUGH 11

An itemized list of the presentations and authors precedes each of the Sessions in this volume.

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Session 1 - Introductory Plenary Session

1-2. "Keynote Address: Space Operations National Infrastructure" - William L. Smith/NASA HQ

1-3. "Role of Rendezvous and Proximity Operations in Integrated Orbital Operations" - Kenneth J. Cox/NASA JSC

1-4. "Mission Control Center Perspectives" - John Cox/NASA JSC

1-5. "Flight Crew Perspectives - SMM" - David Walker/NASA JSC (No printed material is included since the presentation consisted primarily of narration of film sequences from the Shuttle EVA operations)

1-6. "Mission Operations Perspectives" - Kenneth Young and Jerome Bell/NASA JSC

SPACE OPERATIONS NATIONAL INFRASTRUCTURE

WILLIAM L. SMITH
ADVANCED PROGRAMS OFFICE
NASA HEADQUARTERS

RENDEZVOUS AND PROXIMITY OPERATIONS WORKSHOP
LYNDON B. JOHNSON SPACE CENTER
19 FEBRUARY 1985

CONTENTS

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- OBJECTIVES FOR INFRASTRUCTURE
  - CAPABILITIES CONSIDERATIONS
  - COMMERICALIZATION AND PRIVATIZATION OF SPACE

ELEMENTS OF NASA SPACE INFRASTRUCTURE

- NATIONAL SPACE TRANSPORTATION SYSTEM (NSTS)
  - SPACE SHUTTLE
  - ORBIT TRANFER VEHICLES (OTVs)
  - ORBITAL MANEUVERING VEHICLES (OMVs) - STS-BASED
- SPACE STATION PROGRAM ELEMENTS (SSPEs)
  - SPACE STATION
  - SPACE PLATFORMS (CO-ORBITING AND POLAR)
  - ORBITAL MANEUVERING VEHICLES (OMVs) - SPACE STATION-BASED
- SSPE LAUNCH AND MISSION CONTROL CENTERS AND FACILITIES
- USER SPACECRAFT/SPACE SYSTEMS, E.G.
  - SPACE TELESCOPE
  - GAMMA RAY OBSERVATORY (GRO)
  - ADVANCED X-RAY ASTROPHYSICAL FACILITY (AXAF)
- SPACE SUPPORT SYSTEMS, E.G.
  - TRACKING AND DATA RELAY SATELLITE SYSTEM (TDRSS)

NASA OBJECTIVES FOR INFRASTRUCTURE

- DEVELOP CAPABILITIES WITHIN INFRASTRUCTURE TO EFFECTIVELY SUPPORT INTEGRATED SPACE OPERATIONS.
  - ESTABLISH ROUTINE TRANSPORTATION, DELIVERY, RETRIEVAL, AND ON-ORBIT SERVICING FUNCTIONS
  - PROVIDE COST-EFFECTIVE ACCOMMODATION OF USERS
- PAVE WAY FOR COMMERCIAL SPACE VENTURES
- ENCOURAGE MUTUALLY BENEFICIAL INTERNATIONAL PARTICIPATION

INFRASTRUCTURE DEVELOPMENT FOR INTEGRATED SPACE OPERATIONS

- MULTIPLE SPACE PROGRAMS/PROJECTS ARE BEING EVOLVED IN COORDINATED PLAN TO PROVIDE INTEGRATED SPACE OPERATIONS:
  - SPACE SHUTTLE IS DEVELOPING COMPREHENSIVE ON-ORBIT SERVICING CAPABILITIES, IN ADDITION TO TRANSPORTATION AND RETRIEVAL SERVICES, WHICH IS OPENING NEW HORIZONS FOR SPACE SYSTEMS DESIGNS AND OPERATIONS.
  - OMV REPRESENTS MAJOR STEP IN EXPANSION OF ON-ORBIT SERVICES.
  - SPACE SHUTTLE WILL BE PRIMARY LAUNCH SYSTEM FOR SSPE DEPLOYMENT, ACCESS, AND LOGISTICS RESUPPLY.
  - SPACE STATION WILL PROVIDE PERMANENT, SPACE-BASED OPERATIONS:
    - SUPPORT SCIENTIFIC AND COMMERCIAL ENDEAVORS IN SPACE.
    - SERVE AS PARENT TO CO-ORBITING SPACE SYSTEMS.
    - PROVIDE SPACE-BASED WAY STATION/TENDER FOR SPACE TRANSPORTATION.
    - SUPPORT ON-ORBIT ASSEMBLY OF SPACE SYSTEMS
  - OTV WILL EXPAND SERVICES TO GEOSYNCHRONOUS ORBITS.
- LAYS GROUND WORK FOR POTENTIAL FUTURE PROJECTS (LUNAR BASE, INTERPLANETARY FLIGHTS)

MAJOR DESIGN OBJECTIVES IN INFRASTRUCTURE

- COST-EFFECTIVE INTEGRATION OF ELEMENTS OF INFRASTRUCTURE REQUIRES FOLLOWING MAJOR DESIGN OBJECTIVES/CONSIDERATIONS:
  - DESIGN AND IMPLEMENT INFRASTRUCTURE IN STEPS WHICH ALLOW FOR EFFECTIVE GROWTH.
  - WHERE PRACTICAL, PROVIDE FOR COST-EFFECTIVE TECHNOLOGY INFUSION IN SYSTEM DESIGN.
  - FOCUS INFRASTRUCTURE'S CAPABILITIES ON FULFILLING CUSTOMERS' NEEDS AND BE "USER FRIENDLY".
  - INCORPORATE PARTICIPATION OF INTERNATIONAL PARTNERS AS BUILDERS, USERS, AND OPERATORS.
  - EXPLOIT AND ENHANCE MAN'S ROLE IN SPACE; TRANSITION TO PERMANENT PRESENCE IN SPACE.
  - EXPLORE ADVANTAGES OF COMMONALITY AND STANDARDIZATION AMONG THE ELEMENTS OF INFRASTRUCTURE.
  - ESTABLISH EXTENDED LIFE THROUGH MAINTENANCE.

INFRASTRUCTURE AND COMMERICALIZATION/PRIVATIZATION OF SPACE*

- INITIATIVES FOR COMMERCIALIZATION AND PRIVATIZATION OF SPACE
  - "COMMERICAL USE OF SPACE POLICY" ISSUED BY NASA
  - "OFFICE OF COMMERCIAL SPACE TRANSPORTATION" FORMED WITHIN DEPARTMENT OF SPACE TRANSPORTATION.
  - ESTABLISHED NASA's "OFFICE OF COMMERCIAL PROGRAMS"
  - FORMED "NATIONAL COMMISSION ON SPACE"

- MAJOR INITIATIVES PROPOSED IN "COMMERCIAL USE OF SPACE POLICY"
  - SEED-FUNDING FOR PRIVATE SECTOR RESEARCH AND DEVELOPMENT
  - ESTABLISHMENT OF INDUSTRY/UNIVERSITY/GOVERNMENT ADVANCED RESEARCH INSTITUTES
  - AGGRESSIVE PURSUIT OF RESEARCH WHICH ENHANCES AND ENCOURAGES COMMERCIAL SPACE VENTURES
  - SIMPLIFICATION OF PRESENT INTEGRATION PROCESSES, STANDARDIZING AND INCREASING NUMBER OF INTERFACES IN ORBITER
  - AVAILABILITY OF GROUND TEST FACILITIES/EQUIPMENT AT REDUCED PRICES FOR SIMULATION OF SPACE ENVIRONMENTS BY COMMERCIAL VENTURES
  - ENABLE PRIVATE OPERATIONS AND PROTECTION OF PROPRIETARY RIGHTS

* EXCERPTED FROM JANUARY 1985, <u>AEROSPACE AMERICA</u>

ROLE OF RENDEZVOUS AND PROXIMITY OPERATIONS

IN INTEGRATED ORBITAL OPERATIONS

RENDEZVOUS AND PROXIMITY OPERATIONS WORKSHOP

19 FEBRUARY 1984

WILLIAM L. SMITH
SATELLITE SERVICES AND CREW SYSTEMS
NASA HEADQUARTERS

DR. KENNETH J. COX
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PRESENTATION CONTENTS

- BACKGROUND
- WHERE ARE WE TODAY?
  - SUMMARY OF RENDEZVOUS AND PROX OPS HISTORY/CURRENT STATUS
- WHERE DO WE WANT TO BE?
  - LONG-RANGE OBJECTIVES
- HOW DO WE GET THERE?
  - MAJOR PROGRAM THRUSTS

OBJECTIVES OF NASA FOCUS ON RENDEZVOUS AND PROXIMITY OPERATIONS ACTIVITIES

- BUILD ON OUR EXPERIENCE BASE OF RENDEZVOUS AND PROXIMITY OPERATIONS
  - DEFINE TECHNOLOGIES, ADVANCED DEVELOPMENTS, AND OPERATIONS TO ACCOMMODATE USERS WITH COST EFFECTIVITY.
  - DEFINE FLIGHT EXPERIMENTS/DEMONSTRATIONS FOR EARLY OPERATIONAL EXPERIENCE AND USER/CUSTOMER CONFIDENCE BUILDING.
- PROVIDE FOCUSED INTERCHANGE OF INFORMATION, PLANNING, AND POTENTIAL PROGRAM INITIATIVES (NASA, DOD, INDUSTRY, ACADEMIA, INTERNATIONAL)
- EXPLORE DESIGN AND OPERATIONAL COMMONALITY FOR PROXIMITY OPERATIONS AMONG NASA INFRASTRUCTURE (E.G., STS, OMV, OTV, SPACE STATION, PLATFORMS, FREE FLYERS)

POTENTIAL BENEFITS

- ENABLE HIGH-PRODUCTIVITY IN INTEGRATED, PARALLEL OPERATIONS OF MULTIPLE SPACE SYSTEMS
  - MATURE STS OPS
  - INITIAL AND GROWTH SPACE STATIONS
  - EMERGING GROUND- AND SPACE-BASED SYSTEMS

- ENHANCE ACCOMMODATION OF USERS OF SPACE INFRASTRUCTURE
  - REDUCED COSTS
  - EASE OF USE (PLANNING AND OPERATIONS)
  - INCREASED UTILITY/SERVICES

- LAY FOUNDATION FOR COMMERCIALIZATION AND PRIVATIZATION OF SPACE; INCLUDING INTERNATIONAL PARTICIPATION.

SCOPE

- RENDEZVOUS AND PROXIMITY OPERATIONS REPRESENT ONE ELEMENT OF TOTAL INTEGRATED ORBITAL OPERATIONS
  - GROUND LAUNCH AND LANDING OPERATIONS
  - RENDEZVOUS AND PROXIMITY OPERATIONS
  - TRAJECTORY INTEGRATION (BEYOND EARTH-ORBIT OPERATIONS)
  - SPACE-BASED FACILITES OPERATIONS (CHECKOUT, TURNAROUND, AND MAINTENANCE)
  - SATELLITE SERVICES (MAINTENANCE, REPAIR, RESUPPLY)
  - GROUND/SPACE COMMUNICATIONS AND TRACKING
- RENDEZVOUS AND PROXIMITY OPERATIONS REQUIREMENTS DERIVED FROM:
  - OPERATORS (GROUND AND FLIGHT)
  - BUILDERS
  - USERS
- EMPHASIS ON END-TO-END USER OPERATIONS:
  - USER PRODUCTS
  - FLIGHT FACILITIES
  - POCCs (REMOTE)
  - COMMUNICATIONS & TRACKING SYSTEMS
  - OPERATIONS CONTROL CENTERS (GROUND/FLIGHT)

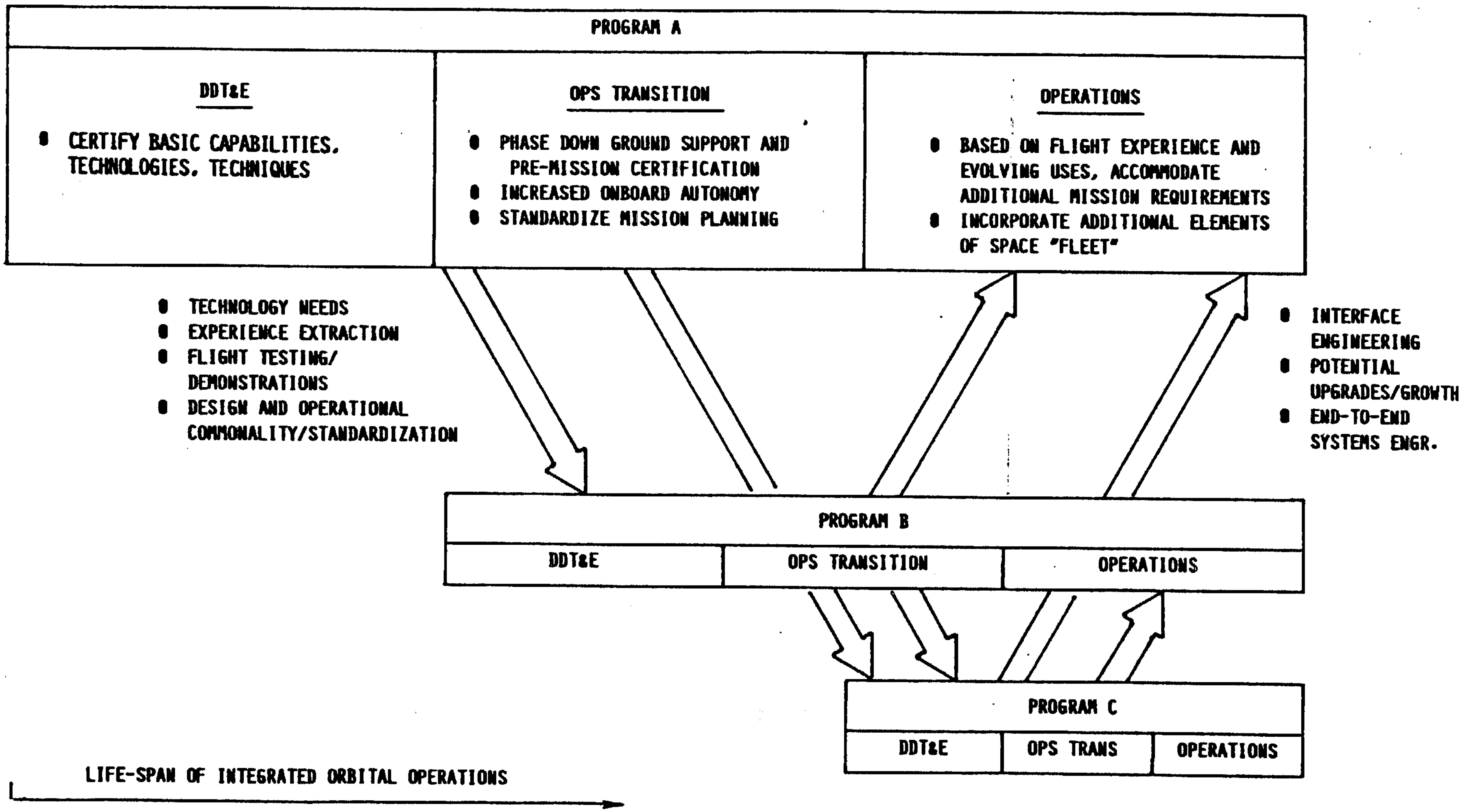
WHAT IS INCLUDED IN RENDEZVOUS AND PROXIMITY OPERATIONS?

- RENDEZVOUS AND PROXIMITY OPERATIONS FUNCTIONS
  - RENDEZVOUS
  - STATIONKEEPING
  - DOCKING/UNDOCKING
  - SPACE TRAFFIC CONTROL
  - EVA/IVA (MANIPULATOR OPERATIONS, TELEOPERATIONS, REMOTE PILOTING)
  - AUTOMATION/ROBOTICS OPERATIONS
  - ORBITAL STAGING
  - TRANSPORTATION FOR SERVICING
  - BERTHING
  - TETHERED OPERATIONS
  - COMPLEX PRECISION MANEUVERING (ROTATIONAL AND TRANSLATIONAL)

MAJOR TECHNICAL AND PROGRAMMATIC CHALLENGES

- TECHNOLOGY AND ADVANCED DEVELOPMENT TO SUPPORT AUTONOMOUS/AUTOMATED CAPABILITIES:
- TECHNOLOGY EMPHASIS - OPERATIONAL EFFICIENCY AND EASE OF GROWTH/UPGRADE.
- PROGRAMMATIC INTEGRATION ACROSS PROJECT/PROGRAM LINES

INTEGRATED ORBITAL OPERATIONS
PROGRAM INTEGRATION

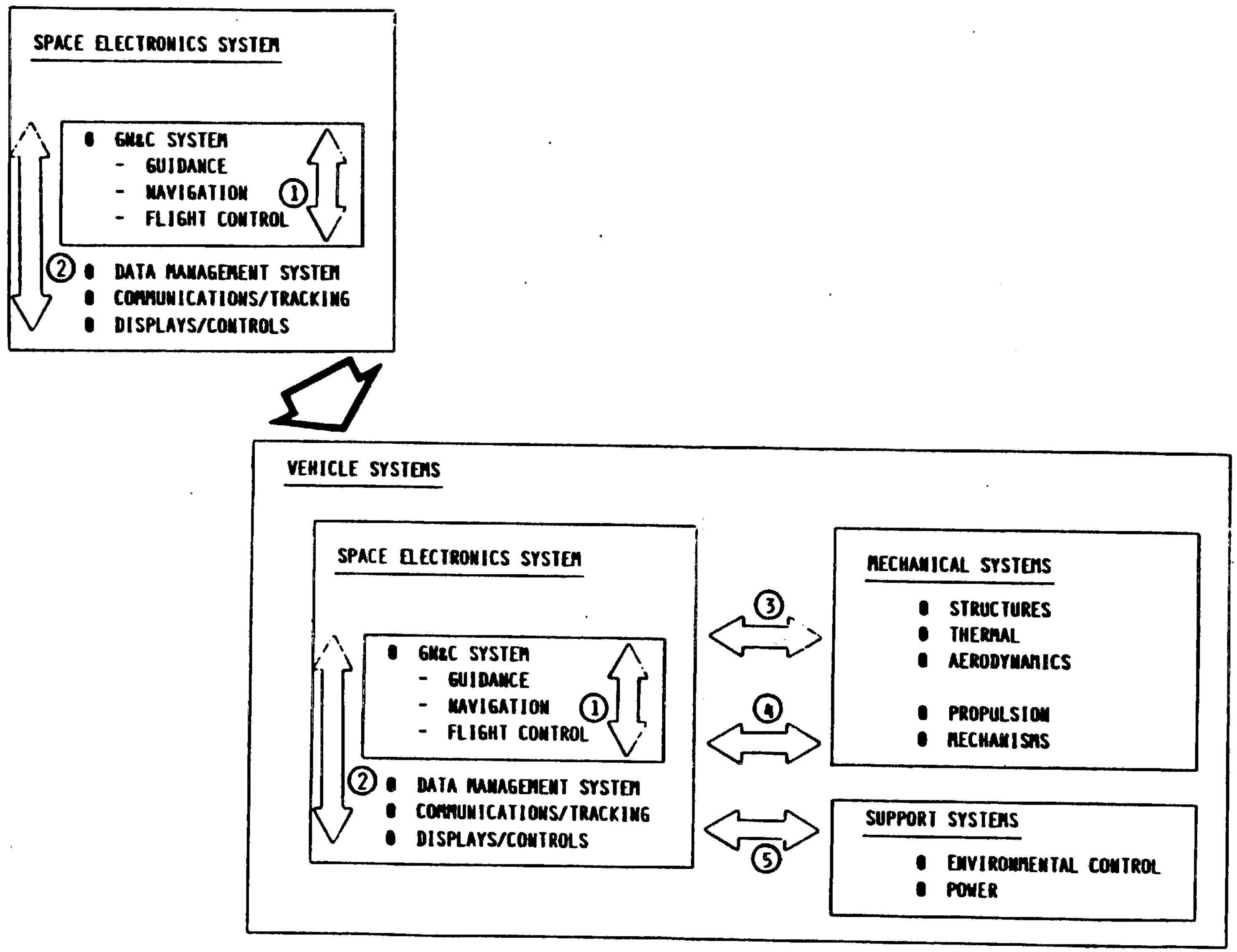


• INTEGRATION MUST BE CARRIED ACROSS ALL PHASES OF PROGRAM/PROJECT AND ACCOMMODATE INFLUX OF NEW PROGRAMS/PROJECTS

ROLE OF INTEGRATION IN PROGRAM PLANS

- A MAJOR CHALLENGE IN RENDEZVOUS AND PROXIMITY OPERATIONS IS EXTENSIVE INTEGRATION REQUIRED AT MULTIPLE LEVELS, PROGRAMMATIC PHASES, AND ACROSS PROJECT/PROGRAM LINES (DEFINED IN FOLLOWING CHARTS)

- NASA MUST ADDRESS THESE INTEGRATIONS EARLY AND IN PARALLEL TO ALLOW EFFECTIVE SUPPORT OF USERS AND COST-EFFICIENT PROGRAMS.


SPACE ELECTRONICS SYSTEM
GN&C SYSTEM
- GUIDANCE
- NAVIGATION
- FLIGHT CONTROL
1
2
DATA MANAGEMENT SYSTEM
COMMUNICATIONS/TRACKING
DISPLAYS/CONTROLS
VEHICLE SYSTEMS
SPACE ELECTRONICS SYSTEM
GN&C SYSTEM
- GUIDANCE
- NAVIGATION
- FLIGHT CONTROL
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DATA MANAGEMENT SYSTEM
COMMUNICATIONS/TRACKING
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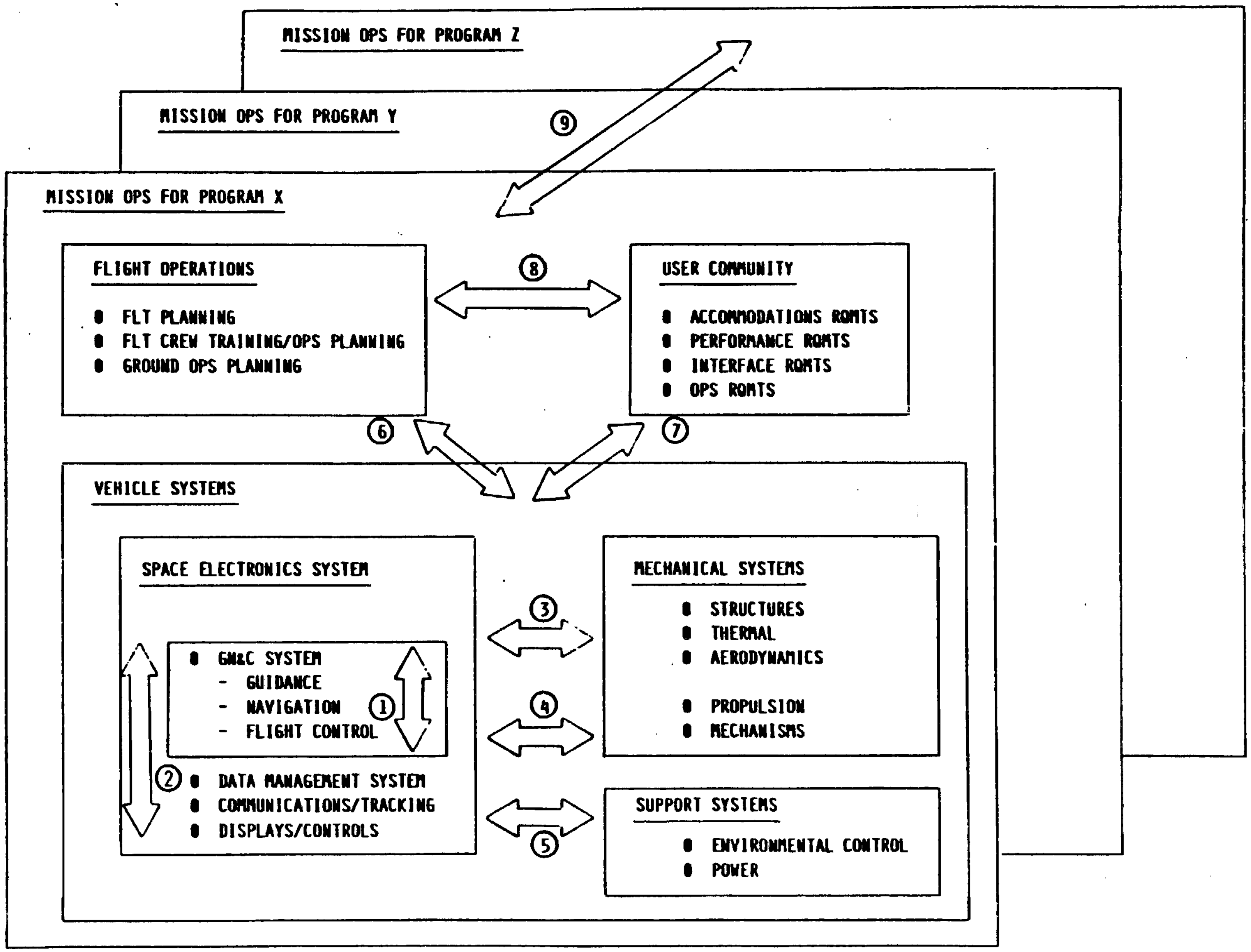
4
5
MECHANICAL SYSTEMS
STRUCTURES
THERMAL
AERODYNAMICS
PROPULSION
MECHANISMS
SUPPORT SYSTEMS
ENVIRONMENTAL CONTROL
POWER


MISSION OPS FOR PROGRAM Z
MISSION OPS FOR PROGRAM Y
MISSION OPS FOR PROGRAM X
9
8
FLIGHT OPERATIONS
• FLT PLANNING
• FLT CREW TRAINING/OPS PLANNING
• GROUND OPS PLANNING
USER COMMUNITY
• ACCOMMODATIONS RQMTS
• PERFORMANCE RQMTS
• INTERFACE RQMTS
• OPS RQMTS
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VEHICLE SYSTEMS
SPACE ELECTRONICS SYSTEM
• GN&C SYSTEM
- GUIDANCE
- NAVIGATION
- FLIGHT CONTROL
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• DATA MANAGEMENT SYSTEM
• COMMUNICATIONS/TRACKING
• DISPLAYS/CONTROLS
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4
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MECHANICAL SYSTEMS
• STRUCTURES
• THERMAL
• AERODYNAMICS
• PROPULSION
• MECHANISMS
SUPPORT SYSTEMS
• ENVIRONMENTAL CONTROL
• POWER

EXAMPLES OF INTEGRATION OF RENDEZVOUS AND PROXIMITY OPERATIONS

- LEVEL 6: INTEGRATION OF VEHICLE SYSTEMS AND OPERATORS (INCLUDES INTEGRATION OF SPACE-BASED AND GROUND BASED OPERATIONS)

  EXAMPLE: HAND-OVER OF CONTROL AUTHORITY BETWEEN GROUND-BASED AND SPACE-BASED OPERATORS DURING DOCKING WITH SPACE STATION.

- LEVEL 7: INTEGRATION OF VEHICLE SYSTEMS AND USERS (SCIENCE AND APPLICATIONS, COMMERICAL, SPACE OPERATIONS)

  EXAMPLE: SPACECRAFT/VEHICLE DESIGN FOR LOGISTICS RESUPPLY AND SERVICING OF USER SYSTEMS.

- LEVEL 8: INTEGRATION OF OPERATOR AND USER

  EXAMPLE: INTEGRATION OF RENDEZVOUS AND PROXIMITY OPERATIONS TECHNIQUES AND SCHEDULES TO EFFICIENTLY SUPPORT TRANSPORTATION, RESUPPLY, AND SERVICING OPERATIONS OF USER SYSTEMS.

EXAMPLES OF INTEGRATION OF RENDEZVOUS AND PROXIMITY OPERATIONS (CON'T.)

- LEVEL 9: INTEGRATION ACROSS PROJECT/PROGRAM LINES FOR INTEGRATED ON-ORBIT FLIGHT OPERATIONS

  - REQUIRED AT ALL INTEGRATION LEVELS
  - EMPHASIS ON COMMONALITY/STANDARDIZATIONS ACROSS PROJECTS/VEHICLES/SYSTEMS
  - ANTICIPATES EVOLUTION OF SPACE FLIGHT SYSTEMS INTO AND OUT OF CONTINUUM OF INTEGRATED ORBITAL OPERATIONS
  - ADDRESSES CLASSICAL MATURING OF A SINGLE PROJECT FROM DDT&E TO OPERATIONS AND EXTRAPOLATION OF CONFIDENCE IN MATURE SYSTEMS TO NEW SYSTEMS.

EXAMPLE: INTEGRATION OF COMMUNICATIONS, TRACKING, AND NAVIGATION CAPABILITIES; ALLOCATION OF COMMAND AND CONTROL AUTHORITY AMONG SPACE STATION, FREE-FLYERS, SPACE FLIGHT SYSTEMS, AND CREWS ON EVA FOR SPACE TRAFFIC CONTROL.

WHERE ARE WE TODAY?

- VALUABLE TECHNICAL AND PROGRAMMATIC EXPERIENCE IN SYSTEMS DESIGNS AND OPERATIONS FOR RENDEZVOUS AND PROXIMITY OPERATIONS HAVE BEEN GAINED IN PAST AND ONGOING PROGRAMS

- GEMINI - FIRST DEMONSTRATION OF MANUAL DOCKING.
  - USED NON-COHERENT RADAR ON CHASE VEHICLE FOR RANGE, RANGE RATE, ANGLE, AND ANGLE RATE MEASUREMENTS FOR RENDEZVOUS.

- APOLLO - SIGNIFICANT MANUAL RENDEZVOUS, PROXIMITY OPERATIONS, AND DOCKING OF ELEMENTS OF THE COMMAND AND SERVICE MODULE (CSM) AND LUNAR MODULE (LM) - EARTH AND LUNAR ORBITS AND COMMAND MODULE HAD TRANSPONDER.
  - CLOSE IN OPERATIONS AT 50 FEET OR LESS WERE MANUAL

- SKYLAB - CSM DOCKING MANEUVERS TO SKYLAB AND INTEGRATED CSM FLIGHT CONTROL MODIFICATIONS TO PROVIDE BACKUP AND RESCUE CONTROL CAPABILITY FOR VARIOUS DOCKED CONFIGURATION.

- APOLLO-SOYUZ - INTEGRATED MANUAL RENDEZVOUS AND DOCKING PROCEDURES AND MODIFIED CSM CONTROL CAPABILITIES TO CONTROL DOCKED APOLLO/SOYUZ CONFIGURATION.

WHERE ARE WE TODAY? (CON'T.)

- SHUTTLE
  - SUCCESSFULLY DEMONSTRATED STANDARD DEPLOYMENT/RETRIEVAL OF SATELLITES WITH RMS/ORBITER MANEUVERS (E.G., SPAS, SPARTAN, LDEF)
  - DEMONSTRATED FLIGHT CREW AND GROUND CREW ADAPTATIONS FOR SUCCESSFUL SOLAR MAXIMUM MISSION REPAIR
    - ORBITER, RMS, MMU, EVA INTEGRATION
    - DEVELOPMENT AND APPLICATION OF EVA SERVICING
  - PALAPA/WESTAR RESCUE MISSIONS SUCCESSFULY ACCOMPLISHED
    - ORBITER, RMS, MMU, EVA INTEGRATION
    - USE OF EVA SERVICING EQUIPMENT (E.G., RMS FOOT RESTRAINTS)
  - ORBITAL REFUELING SYSTEM DEMONSTRATION
  - DEPLOYMENT AND RETRIEVAL OF TETHERED SATELLITE SYSTEMS ARE PLANNED
  - KU-BAND CAPABILITY WITH AND WITHOUT TRANSPONDERS

WHERE DO WE WANT TO BE?

(LONG-RANGE OBJECTIVES)

- ESTABLISH APPROACHES TO AUTONOMY/AUTOMATION IN RENDEZVOUS AND PROX OPS
  - DEGREE OF GROUND PARTICIPATION
  - OPERATIONS MODES:
    - DIRECT MAN-IN-THE-LOOP
    - AUTOMATIC WITH MANUAL OVERRIDE
    - AUTOMATIC WITH MANUAL SYSTEM SUPERVISION

- INCORPORATE ELEMENTS OF SPACE SYSTEMS INFRASTRUCTURE INTO CONTINUOUS ORBTIAL OPERATIONS, WITH EMPHASIS ON COST EFFECTIVITY AND PRODUCTIVITY
  - PROMOTE STANDARD CORE SPACE DESIGNS AND OPERATIONS
  - IMPLEMENT INTEGRATED FLIGHT TEST/FLIGHT DEMONSTRATION PROGRAM TO ACCELERATE AND ASSIMILATE TECHNOLOGY ADVANCES
  - ESTABLISH THE ROLES OF GROUND TESTS/ENGINEERING ANALYSIS/FLIGHT TESTS IN ADVANCED DEVELOPMENT.

LONG-RANGE OBJECTIVES (CON'T.)

- IMPLEMENT SPACE TRAFFIC CONTROL
  - IDENTIFICATION OF COMMON/COMPATIBLE EQUIPMENT AND INTERFACES.
  - ESTABLISH CRITERIA FOR COMMAND AND CONTROL AUTHORITY, HAND-OVER PROCESS.
- PROVIDE SPACE ELECTRONICS AND MECHANICAL SYSTEMS SUPPORT TO INTERFACE ENGINEERING
  - IMPLEMENTATION OF "STANDARDIZED" INTERFACES AMONG ELEMENTS OF SPACE "FLEET"
  - EARLY SPACE ELECTRONICS/MECHANICAL SYSTEMS INTEGRATION
  - DEVELOP TEST FACILITIES TO DESIGN AND VERIFY INTERFACES AND PERFORMANCE OF INTERACTING SPACE FLIGHT SYSTEMS.

HOW DO WE GET THERE?

- FOCUS TECHNOLOGY AND ADVANCED DEVELOPMENT ACTIVITIES VIA A PHASED, INTEGRATED PLAN, ENCOMPASSING:
  - RESEARCH AND TECHNOLOGY
  - SIMULATIONS/TEST FACILITIES
  - FLIGHT OPERATIONS
  - ADVANCED DEVELOPMENT
  - FLIGHT TESTS/FLIGHT DEMONSTRATIONS

- USE MECHANISMS SUCH AS THIS WORKSHOP TO COALESCE THE THOUGHTS OF THE TECHNICAL COMMUNITY.
  - REVIEW CURRENT TECHNOLOGY, ADVANCED DEVELOPMENT, AND PROGRAM PLANS.
  - DEVELOP SPECIFIC FOCUS AND PRIORITIES, WITH REALISTIC OBJECTIVES. IDENTIFY HIGH PAYOFF CAPABILITIES.

- IMPLEMENT EVOLUTIONARY, BUILDING-BLOCK APPROACH TO DEVELOPMENT OF TECHNOLOGIES AND CAPABILITIES:
  - USE ORBITER AND OMV AS PATH FINDERS IN PROGRAM DEVELOPMENT AND DEMONSTRATION
  - INCORPORATE FLIGHT TESTS TO PROVIDE EARLY FLIGHT DEMONSTRATIONS AND CONFIDENCE BUILDERS. ORBITER AND OMV AS INITIAL FLIGHT TEST BEDS.
  - USE SPACE STATION AS POTENTIAL INFLIGHT TECHNOLOGY FACILITY.

MAJOR THRUSTS FOR RENDEZVOUS AND PROXIMITY OPERATIONS

- DEVELOP RENDEZVOUS AND PROXIMITY OPERATIONS SERVICES KEYED TO USER REQUIREMENTS.
- DEVELOP PRAGMATIC, OPERATIONALLY COST-EFFECTIVE AUTONOMY/AUTOMATION TECHNIQUES.
- PROVIDE EARLY FLIGHT DEMONSTRATIONS OF CAPABILITY
- ESTABLISH PLAN FOR EVOLVING SPACE TRAFFIC CONTROL DEVELOPMENT AMONG ELEMENTS OF SPACE FLEET.

EH / Ken C

NASA Lyndon B. Johnson Space Center MISSION OPERATIONS DIRECTORATE	SUBJECT:	NAME:	
		DATE:	PAGE

RENDEZVOUS/PROXIMITY OPERATIONS SHUTTLE

FLIGHT EXPERIENCE

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JSC/DA8/X4372
FEBRUARY 19, 1985

NASA Lyndon B. Johnson Space Center MISSION OPERATIONS DIRECTORATE	SUBJECT: RENDEZVOUS/PROXIMITY OPERATIONS FLIGHT EXPERIENCE	NAME: DA8/J. T. Cox	
		DATE: Feb. 19, 1985	PAGE 1

OUTLINE

- BACKGROUND (SHUTTLE APPLICATION AND EQUIPMENT USED)
- TYPICAL RENDEZVOUS PROXIMITY OPERATIONS PROFILES
- ROLES OF ONBOARD CREW AND CONTROL CENTER TEAM
- LESSONS LEARNED BY FLIGHT
- SUMMARY OF SHUTTLE EXPERIENCE

- DEFINITIONS
  - RENDEZVOUS - ALL ORBITER OR PAYLOAD MANEUVERS (ORBIT SHAPING, PHASING, INTERCEPT INITIATION) UP TO INITIATION OF PROXIMITY OPERATIONS
  - PROXIMITY OPERATIONS - POST RENDEZVOUS PHASE WHERE THE RELATIVE SEPARATION RANGE AND RANGE RATE ARE SUFFICIENTLY SMALL (<1000 FEET, <1 FOOT PER SECOND) SUCH THAT RENDEZVOUS OPERATIONS ARE NOT REQUIRED TO RESTORE PROXIMITY
- SHUTTLE RENDEZVOUS/PROXIMITY OPERATIONS EXPERIENCE TO DATE
  - STS-7: SPAS
  - STS 41-B: BALLOON, MANNED MANEUVERING UNIT (MMU)
  - STS 41-C: SOLAR MAXIMUM SATELLITE, MMU
  - STS 51-A: PALAPA, WESTAR, MMU
- RENDEZVOUS/PROXIMITY OPERATIONS - NEAR TERM PLANNING
  - STS 51-D LONG DURATION EXPOSURE FACILITY
  - STS 51-F SPACELAB (PLASMA DIAGNOSTIC PACKAGE)
  - STS 51-G SPARTAN 1

- STS PROBLEM - RENDEZVOUS/PROXIMITY OPERATIONS
  - DEFINE ACCEPTABLE LAUNCH WINDOW FOR RENDEZVOUS
    - ASCENT PERFORMANCE MARGIN (TRADE INSERTION ALTITUDE AND PROPELLANT AVAILABLE TO MANEUVER)
    - PHASING BOUNDARIES AT TIME OF LAUNCH (ALTTITUDE CAPABILITY PLUS CATCH UP ANGLE)
    - PLANE ADJUST CAPABILITY DURING LAUNCH PHASE
    - OTHERS (LIGHTING, TANK DISPOSAL, NUMBER OF RENDEZVOUS, ETC.)
  - PERFORM RENDEZVOUS/MANEUVERS WITHIN ORBITER PROPELLANT BUDGET AND AS COMPATIBLE WITH FLIGHT CONSTRAINTS (ORBITER PLUS PAYLOADS)
    - EFFICIENT TRANSLATION MANEUVERS TO SAVE FORWARD PROPELLANT AND TO ACCOMPLISH OTHER PAYLOAD TASKS ON SAME FLIGHT
      - DEPLOYMENTS
      - CELESTIAL, EARTH VIEWING DATA TAKES
      - EXTRAVEHICULAR (EVA) ACTIVITIES

- MAINTAIN SUFFICIENT RESERVES FOR ENTRY DEORBIT PLUS SET UP CROSSRANGE AND LIGHTING FOR LANDING OPPORTUNITY
- PERFORM MANEUVERS DURING CREW AWAKE PERIOD
- DURING TERMINAL PHASE SET UP LIGHTING AND FIX RELATIVE MOTION GEOMETRY

• PROXIMITY OPERATIONS
  - AVOID CONTACT OF PAYLOAD WITH ORBITER
  - ADAPT TO PAYLOAD UNIQUE CONSTRAINTS/REQUIREMENTS
    • CONTAMINATION, SENSITIVE SURFACES, RF SENSITIVITY (I.E., ORBITER RADAR)
    • SOLAR PANEL POINTING
    • MINIMIZE PAYLOAD MOTION DISTURBANCE PRIOR TO CAPTURE
    • APPROACH GEOMETRY - PAYLOAD OR ORBITER PERFORMS ATTIUTDE MANEUVERS

NOTE: THESE HELD DEFINE:

- DIGITAL AUTOPILOT CONFIGURATION
- STATIONKEEPING RANGE DAYLIGHT/DARKNESS
- APPROACH TECHNIQUE (V-BAR, R-BAR, INERTIAL)
- RANGING TECHNIQUE/DEVICES

– PERFORM KEY DEXTERITY OPERATIONS UNDER GOOD LIGHTING CONDITIONS

- OVERHEAD, AFT WINDOWS
- REMOTE MANIPULATOR SYSTEM (RMS) AND PAYLOAD BAY TV CAMERAS
- ORBITER LIGHTS, SUN ANGLE

- EQUIPMENT USED FOR RENDEZVOUS (NAVIGATION) TASKS - GROUND COMPUTATIONS
  - S-BAND (GROUND OR TDRS), C-BAND TRACKING OF ORBITER STATE
  - USER OR GSTDN TRACKING OF TARGET STATE

- EQUIPMENT USED FOR RELATIVE NAVIGATION - GROUND AND ONBOARD COMPUTATIONS
  - ORBITER STAR TRACKER (100-200 NMI)
  - ORBITER KU-BAND RADAR (0-20 NMI)
  - COAS (VISUAL) - (100-200 NMI) - FUNCTION OF TARGET VISIBILITY
- EQUIPMENT USED FOR RANGE/RANGE RATE DATA DURING PROXIMITY OPERATIONS
  - RADAR - (BEYOND 70 FEET) RANGE, RANGE RATE, ANGLE, ANGLE RATE (NOISY)
  - COAS - SUBTENDED ANGLE
  - CCTV PAN/TILT PLUS OVERLAYS (SUBTENDED ANGLE)
  - BINOCULARS - SUBTENDED ANGLE
  - LASER - RANGE, RANGE RATE (NOISY) - NO LONGER CARRIED
  - LIGHTING - BAY, DOCKING, RMS, SPAS AND MMU RUNNING LIGHTS, LDEF REFLECTORS, STREAMLITE
  - PARALLAX RANGE FINDER - RANGE

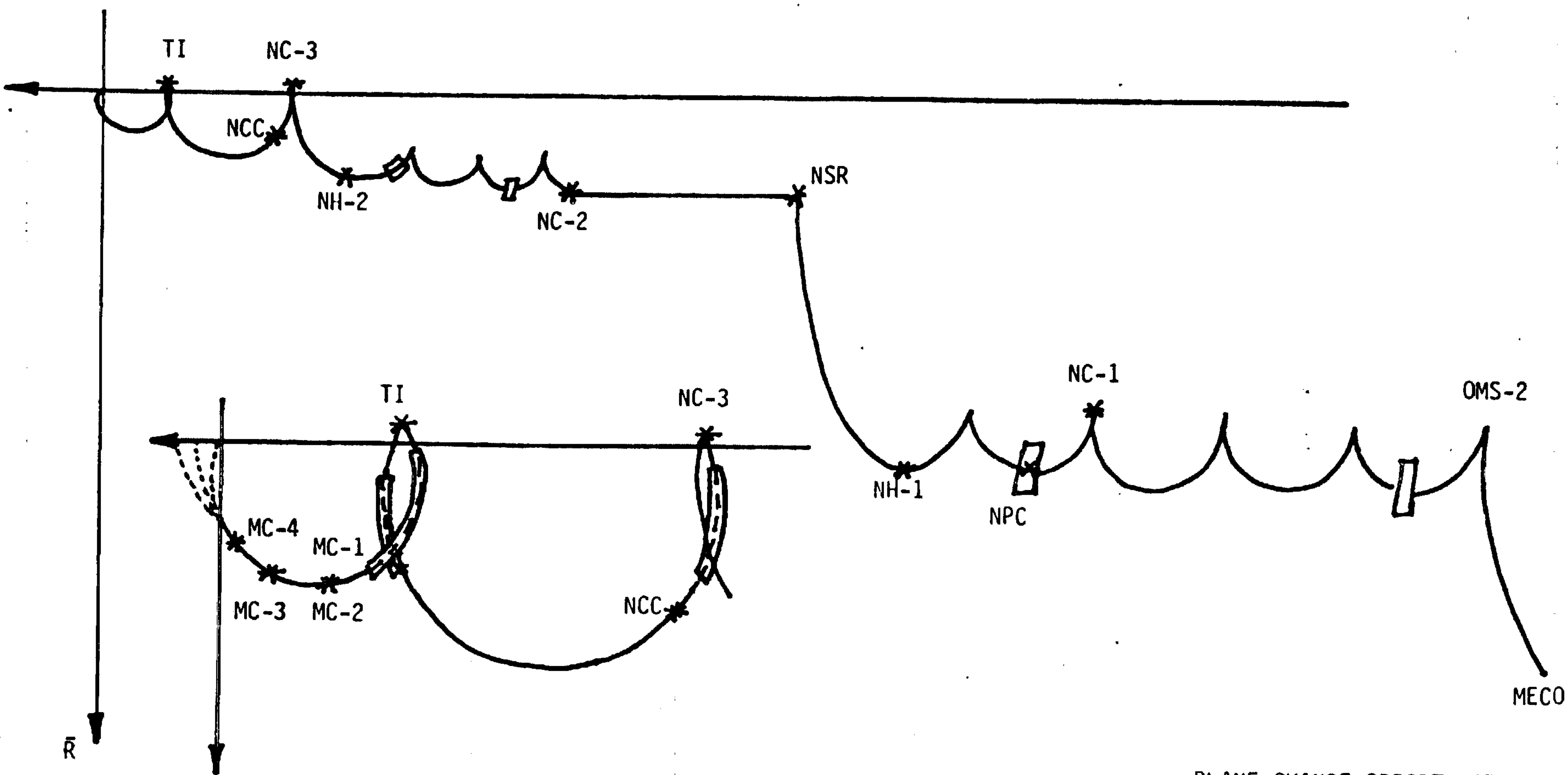
- OTHER EQUIPMENT USED DURING PROXIMITY OPERATIONS
  - ORBITER - PRIMARY REACTION CONTROL SYSTEM (PRCS) - "LOW Z" MODE
  - COMMUNICATIONS EQUIPMENT - PAYLOAD INTERROGATOR
  - PAYLOAD RETENTION LATCHES
  - MANNED MANEUVERING UNIT
  - REMOTE MANIPULATOR SYSTEM
  - SPECIAL PURPOSE PAYLOAD HANDLING EQUIPMENT: FLIGHT SUPPORT SYSTEM (FSS), RELEASE/ENGAGE MECHANISM, ETC.
  - UMBILLICAL MATE/DEMATE DEVICES

- LAUNCH DAY
  - LAUNCH WINDOW DEFINED TO OCCUR AS RENDEZVOUS TARGET PLANE CROSSES LAUNCH SITE. WINDOW DURATION IS FUNCTION OF PLANE CHANGE CORRECTION PERFORMANCE CAPABILITY AND CATCH UP ANGLE ADJUST CAPABILITY (ALTITUDE AND TIME)
  - ASSURE THAT ABORT REGION AND OTHER PAYLOAD CONSTRAINTS ARE SATISFIED (SUNLIGHT, DEPLOYMENT/TRANSFER ORBIT GROUND TRACKS, ETC.)
- TYPICAL PROFILE - RENDEZVOUS
  - ACCOMPLISH RENDEZVOUS:
    1. REDUCE CATCHUP ANGLE/ANGLE RATE BY RAISING ORBITER ALTITUDE
    2. ESTABLISH CO-ELIPTIC ORBIT
    3. TARGET MANEUVERS TO REACH TRANSFER INITIATE (TI) POINT (SAME ORBIT AS TARGET, BUT TRAILING 8-10 NMI). TARGETING MUST ALSO PROVIDE FOR ARRIVAL AT MANUAL TERMINATE PHASE START POINT (<2 NMI)
    4. PERFORM TRANSFER BURN (INTERCEPT TARGET IN ONE ORBIT) PLUS MIDCOURSE CORRECTIONS

5. ESTABLISH VELOCITY MATCH AND INITIATE PROXIMITY OPERATIONS (<1000 FEET)

6. PERFORM ALL MANEUVERS DURING NORMAL CREW WORKDAY

7. AFTER ARRIVAL AT PROXIMITY OPERATIONS START POINT PROVIDE SUFFICIENT TIME/LIGHTING TO ACCOMPLISH FINAL CAPTURE ACTIVITIES



PLANE CHANGE OPPORTUNITIES

TRACKER DATA TAKES

NC PHASING BURNS
NH ALTITUDE ADJUST BURNS
NSR COELIPTIC BURN
MC MID COURSE CORRECTIONS
TI TRANSFER INITIATE

TYPICAL RENDEZVOUS/PROXIMITY OPERATIONS PROFILE

- TYPICAL PROFILE - PROXIMITY OPERATIONS
  - ORBITER APPROACHES A QUIESCENT VEHICLE WHICH HAS BEEN VERIFIED TO BE SAFE
  - TARGET MONITORED THROUGH OVERHEAD WINDOW COAS (-Z). ZERO INERTIAL LINE-OF-SIGHT RATE MAINTAINED UNTIL V-BAR REACHED
  - USE BRAKING GATE TECHNIQUE TO NULL CLOSING RATE

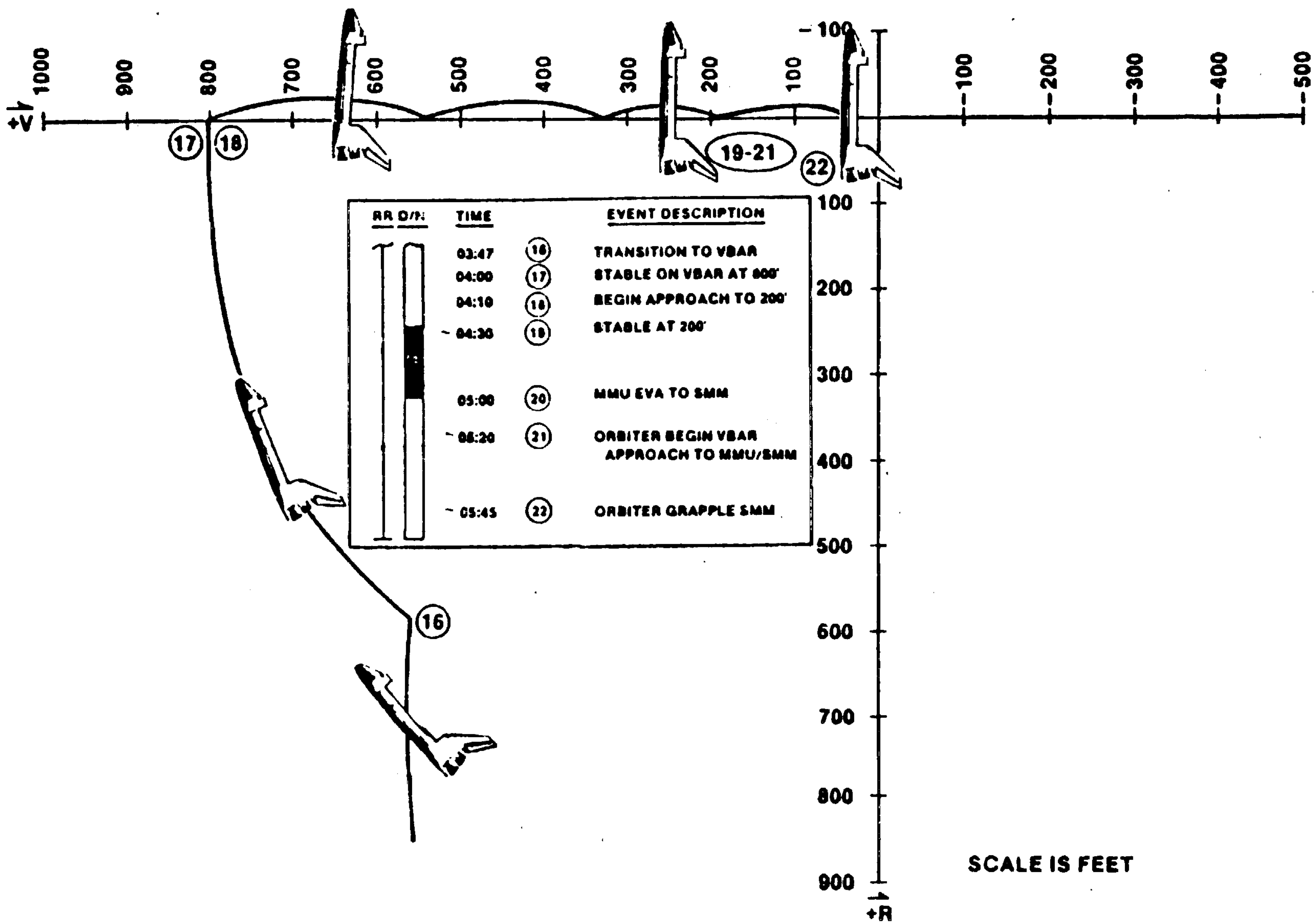
1000 FEET	1.0 FPS
500 FEET	.5 FPS
200 FEET	.2 FPS
100 FEET	.1 FPS

  - USE "LO Z" PRCS MODE FROM TIME THAT PLUMES WILL CAUSE SIGNIFICANT TARGET MOTION/CONTAMINATION (PREFLIGHT ANALYZED FOR EACH PAYLOAD) UNTIL PAYLOAD IS WITHIN THE "QUIET ZONE" ABOVE CARGO BAY AT ≤60 FEET
  - STATION KEEP USING PRCS NORMAL Z FOR TRANSLATION CORRECTIONS AND VERNIER JETS (VRCS) FOR ATTITUDE CONTROL
  - APPROACH CONSTRAINTS MAY DICTATE ONE OF THE FOLLOWING CLOSURE TECHNIQUES:

V-BAR:	CLOSE IN ALONG VELOCITY VECTOR
R-BAR:	CLOSE IN ALONG RADIUS VECTOR
INERTIAL:	FLYAROUND TARGET AT FIXED RADIAL DISTANCE USING FIXED ROTATION RATE

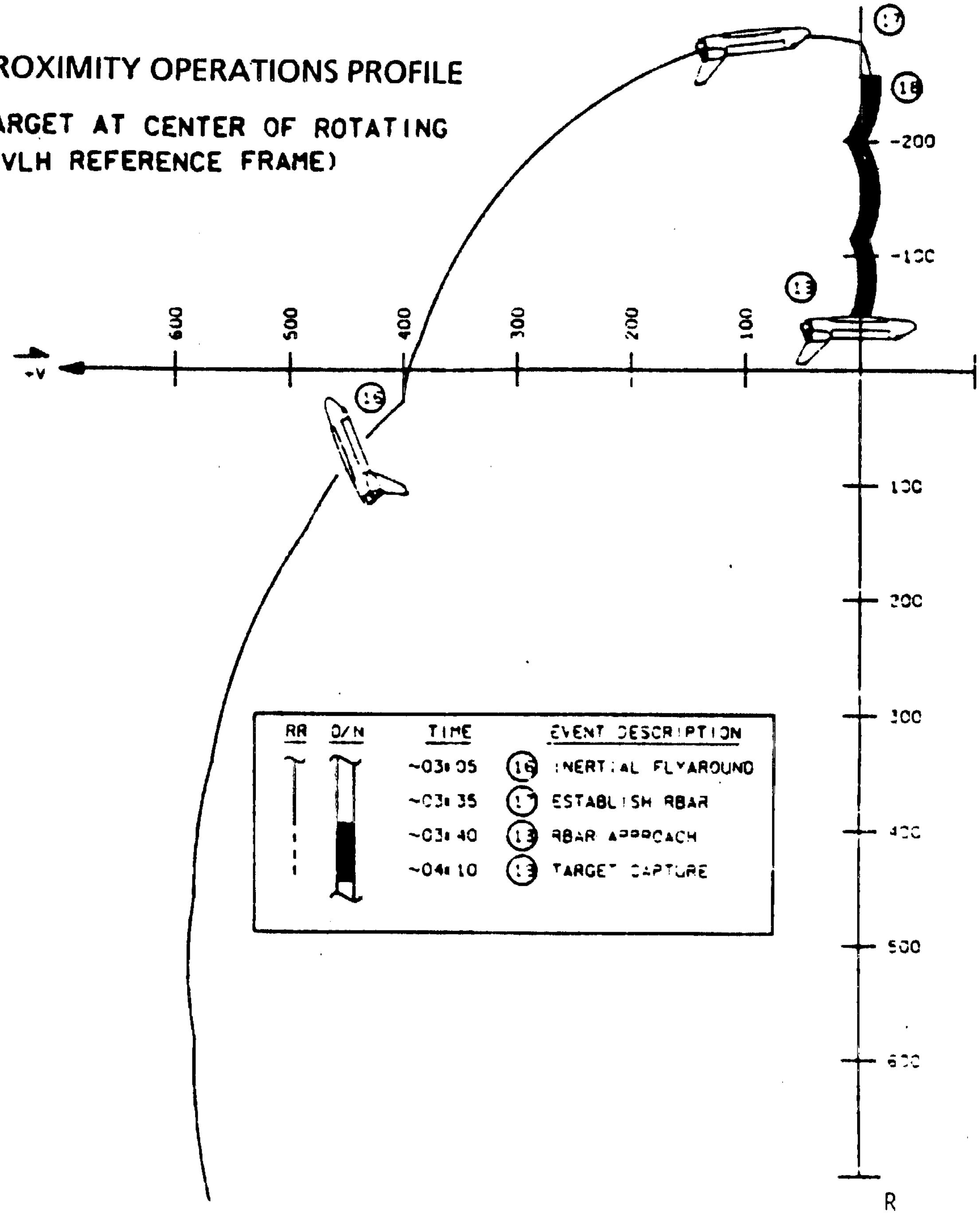
- PERFORM PAYLOAD/ORBITER ATTITUDE/POSITION ADJUSTMENTS AS REQUIRED TO FACILITATE CAPTURE AND MINIMIZE PLUME DISTURBANCES
  - SPAS - ATTITUDE CONTROLLED FROM ORBITER USING KEYBOARD ENTRIES TO GPC SPEC DISPLAYS
  - SOLAR MAX - CONTROLLED BY PAYLOAD OPERATIONS CONTROL CENTER - NO PROXIMITY OPERATIONS CONTROL OTHER THAN SPIN STABILIZATION
  - PALAPA, WESTAR - SPIN STABILIZED WITH NO ACTIVE CONTROL DURING PROXIMITY OPERATIONS
  - PORTABLE FOOT RESTRAINT - LOW MASS EASILY RETRIEVED BY EVA CREW AFTER ORBITER "RESCUE" MANEUVERS PERFORMED - LO Z TRANSLATIONS, ALL IN QUIET REGION
  - LONG DURATION EXPOSURE FACILITY - GRAVITY GRADIENT STABILIZED WITH GG DAMPER ASSIST. REQUIRES R-BAR APPROACH (CONTAMINATION PLUS CONTROL OF RMS OPTIONS)

SOLAR MAX RENDEZVOUS PROFILE
(SMM AT CENTER OF ROTATING LVLH REFERENCE FRAME)



LDEF PROXIMITY OPERATIONS PROFILE

(TARGET AT CENTER OF ROTATING LVLH REFERENCE FRAME)



- ROLE OF FLIGHT CREW (SIMULTANEOUS ACTIVITY - MINIMUM OF 4)
  - COMMANDER PERFORM PILOTING TASKS
    - EXECUTE GROUND OR ONBOARD COMPUTED MANEUVERS PLUS BRAKING GATES, STATIONKEEPING
    - EVALUATE MANEUVER EXECUTION AND PERFORM APPROPRIATE BAILOUT MANEUVER (PROPELLANT LIMITS)
  - SECOND CREWMAN MONITOR SENSOR PERFORMANCE AND INITIATE COMPUTATIONS FOR MANEUVERS (RADAR, STAR TRACKER, COAS DATA)
    - RADAR RANGE/RANGE RATE PROFILE ANGLE/ANGLE RATE
    - COAS LINE OF SITE
    - ESTABLISH LOCK AND CONFIGURE PAYLOAD COMMUNICATIONS EQUIPMENT
  - THIRD-FIFTH CREWMEN PREPARE FOR (ACTIVATE AND CHECKOUT) AND PERFORM CAPTURE (RMS, MMU/EVA, SPECIAL PURPOSE DEVICE ETC.)
    - ACTIVATE AND CHECKOUT CAPTURE DEVICES (RMS, EVA SUIT, EVA EQUIPMENT)
    - TRANSMIT COMMANDS AND MONITOR DATA FROM SATELLITE

- PERFORM CAPTURE WITH RMS OR SPECIAL CAPTURE DEVICE OR VIA SPECIAL EVA TECHNIQUE

- MONITOR EVA CREWMEN AND PHOTO DOCUMENT CRITICAL TASKS

- ROLE OF MISSION CONTROL

  - MAINTAIN ORBITER STATE VECTOR - PERIODICALLY UPLINK NEW STATE AS RESULT OF TRACKING DATA

  - PROVIDE AND MAINTAIN TARGET STATE TO ORBITER (RESULT OF PAYLOAD SUPPLIED DATA)

  - COMPUTE MANEUVERS WHICH ARE NOT COMPUTED ONBOARD - ALL MANEUVERS PRIOR TO WELL CONVERGED ORBITER RELATIVE MOTION DATA (MANEUVERS PRIOR TO NCC)

  - MONITOR AND EVALUATE (CHECK) ORBITER MANEUVER SOLUTIONS USING ORBITER DERIVED RELATIVE MOTION NAVIGATION DATA

  - MONITOR PERFORMANCE OF ORBITER SYSTEMS/CONSUMABLES STATUS AND RECOMMEND ALTERNATE/CONTINGENCY PROCEDURES AS APPROPRIATE TO ACCOMPLISH CAPTURE

  - MAINTAIN BAILOUT MANEUVER/RECOVERY PLAN FOR FAILURE TO EXECUTE PLANNED BURNS

- STS-7 - SPAS (PROXIMITY OPERATIONS) - DEPLOY, SEPARATE, APPROACH USING INERTIAL FLY AROUND AND V-BAR, PLUME SURVEY
  - RADAR PERFORMANCE WAS GOOD (ANGLE RATE DATE NOISY)
  - RMS OPERATIONS WORKED WELL, VARIABLE RMS TIP-OFF RATES AT RELEASE
  - VERIFIED PROPELLANT COSTS FOR V-BAR AND INERTIAL FLY AROUND
  - PLUME SUSCEPTABILITY OUTSIDE QUIET ZONE IS DRAMATIC (NOT LO Z)
    - NEED TO CAREFULLY PLAN RELATIVE TRAJECTORY/DIGITAL AUTO PILOT CONFIGURATIONS
- STS 41-B USE SPAS AS DOCKING TARGET FOR MMU, PERFORM FIRST MMU TEST FLIGHTS, RENDEZVOUS WITH BALLOON TARGET, (RESCUE FOOT RESTRAINT)
  - RENDEZVOUS
    - STAR TRACKER AND RADAR SENSORS WORKED BETTER THAN SPEC (NO RENDEZVOUS DUE TO BALLOON SYSTEM DEBRIS FOLLOWING EXPLOSION)

- PROXIMITY OPERATIONS
  - RADAR WAS USEFUL DURING 70 TO 400 FOOT TRANSLATION RANGE ON MMU
  - MMU RUNNING LIGHTS WERE ESSENTIAL TO TRACK MMU IN DARKNESS
  - LASAR RANGING WAS MARGINAL, RANGE RATE WAS TOO NOISY TO USE (LASAR SYSTEM POINTING WAS TEDIUS AND REQUIRED FULL TIME ATTENTION FROM ONE CREWMAN)
  - MMU RESCUE TECHNIQUE WAS DEVELOPED PREFLIGHT AND CONCEPTUALLY VERIFIED DURING RETRIEVAL OF FOOT RESTRAINT
  - TETHERED FLIGHT OF MMU WAS NOT PERFORMED DUE TO PREFLIGHT EVALUATION OF TETHER MANAGEMENT AND BOUNCE BACK EFFECTS
  - MMU RESCUE PLAN DEVELOPED AS ORBITER ACTIVE (vs OTHER MMU) TO MINIMIZE NUMBER OF ACTIVE VEHICLES PLUS ORBITER PERFORMANCE "WELL KNOWN."
  - MMU PROPELLANT (N_2) CONSUMPTION WAS HIGH AND FLIGHT ACTIVITIES SOMEWHAT LIMITED
  - RMS MALFUNCTION OCCURRED WHICH CANCELLED THE ROTATING DOCKING TEST - RMS KNOWN TO BE SUSCEPTIBLE TO SINGLE POINT FAILURES. CONSIDERATION SHOULD ALWAYS BE GIVEN TO PROVIDING REDUNDANT CAPTURE CAPABILITY IF POSSIBLE

- BAILOUT* MANEUVER EXECUTED IN RESPONSE TO BALLOON SYSTEM EXPLOSION. TO ASSURE ORBITER/TARGET BALLOON DID NOT COME INTO CONTACT.

  *BAILOUT MANEUVERS ARE PREFLIGHT DEVELOPED TO ASSURE THAT RENDEZVOUS/ CAPTURE CAN BE SAFELY ABORTED FROM ANY POINT IN TIMELINE

● STS 41-C CAPTURE SOLAR MAXIMUM MISSION SATELLITE USING MMU FLYAROUND AND SPECIAL DOCKING DEVICE (RMS BACKUP) PLUS REPAIR AND DEPLOY WORKING SATELLITE

• RENDEZVOUS

  - SPACECRAFT (SMM WAS HIGHLY VISIBLE AND WAS PICKED UP IN STAR TRACKERS EARLY IN RENDEZVOUS (~ 200 NMI)
  - STAR TRACKER PASSES WERE OCCASSIONALLY VERY NOISY DUE TO SMALL DIFFERENCES IN INERTIAL MEASUREMENT UNIT MIDVALUE SELECT ROUTINE IN GPC SOFTWARE
  - FORWARD RCS FUEL SAVINGS TECHNIQUES DEVELOPED FOR SECOND RENDEZVOUS ATTEMPT (MANEUVER TO ATTITUDE USING TAIL ONLY PRCS, DELETE MULTIAXIS BURNS WHERE POSSIBLE, HOLD ATTITUDE ON VRCS)
  - BAILOUT MANEUVER STRATEGY DEVELOPED FOR ALL POINTS ALONG RENDEZVOUS AND PROXIMITY OPERATIONS TRAJECTORY TO ASSURE UNPLANNED CONTACT DOES NOT OCCUR. BAILOUT IMPLEMENTED AT END OF FIRST CAPTURE ATTEMPT

- ORBITER SEPARATION FROM SPACECRAFT AFTER FIRST RENDEZVOUS OCCURRED FASTER THAN PLANNED. PROBLEM HAD PREVIOUSL BEEN SUSPECTED/OBSERVED AND IS STILL UNDER ANALYSIS. SUSPECT ORBITAL ENERGY GROWTH DUE TO ORBITER PLUME IMPINGEMENT/SCARFING DURING ATTITUDE CONTROL PULSES WITH VRCS
    - IMPACT IS PHASING ADJUSTMENTS TO CONTROL SUBSEQUENT RENDEZVOUS

• PROXIMITY OPERATIONS

- CAPTURE SYSTEMS (BOTH HALVES) MUST BE WELL KNOWN FOR CASE AT HAND - PREFERABLY BUILT BY SAME ORGANIZATION
- ANGULAR MOMENTUM OF SPACECRAFT MAY BE EASILY UPSET IF CAPTURE NOT SUCCESSFUL ON FIRST ATTEMPT
- LARGE MASSES ARE RELATIVELY EASY TO HANDLE MANUALLY (UP TO 500 LBS)
- RELATIVE MOTION CUES TO ORBITER OR MMU CREWMEN ARE FUNCTION OF TARGET MOTION - PROXIMITY OPERATIONS TRAINING WILL BE FUNCTION OF EXPECTED MOTION - UNEXPECTED TARGET MOTION MAY RESULT IN HIGH PROPELLANT CONSUMPTION
- ORBITER PLUME EFFECTS CAN BE SIGNIFICANT (SURFACE AREA AND ORIENTATION DEPENDENT) EVEN WHEN SPACECRAFT IS IN QUIET ZONE

NASA Lyndon B. Johnson Space Center MISSION OPERATIONS DIRECTORATE	SUBJECT: LESSONS LEARNED (CONT'D)	NAME: DA8/J. T. COX	
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- PLUME EFFECTS FROM MMU ARE SMALL AND DO NOT APPEAR TO RESULT IN NOTICEABLE MOTION ON SPACECRAFT (5000 LBS)

- ORBITER TRANSLATIONS AND ROTATIONS USING "LO Z" MODE WASTES UP TO 12 TIMES AMOUNT OF IDEAL PROPELLANT. "LO Z" ONLY EFFECTIVE FOR SINGLE Z AXIS BRAKING AND MUST BE USED JUDICIOUSLY

- ORBITER ACTIVE MMU RESCUE ANALYZED PREFLIGHT AND FOUND TO BE VERY COSTLY FOR 3 BODIES (AVOID COLLISION, KEEP VIEW OF SATELLITE) RESULTING IN RELATIVELY HIGH PROPELLANT BUDGET TO ALLOW MMU FREEFLIGHT (~3X MMU ALONE)

- PREFLIGHT DEVELOPED RMS GRAPPLE TECHNIQUE USED FOR CAPTURE WAS BUILT AS A BACKUP TO MMU TECHNIQUE USED RMS BEYOND ADVERTISED LIMITS WHICH EXPERIENCE INDICATED COULD BE EXCEEDED FOR THIS CASE

- STS 51-A CAPTURE AND RETURN OF PALAPA AND WESTAR COMMUNICATION SATELLITES

  MMU ROTATING DOCKING WITH STINGER (AXIAL APPROACH)

  MANUAL POSITIONING OF SATELLITE

  SIMULTANEOUS EVA PLUS PROXIMITY OPERATIONS (3 BODY)

  - RENDEZVOUS
    - SPACECRAFT VISIBILITY BETTER THAN PREDICTED. PICKED UP IN STAR TRACKER AT >100 NMI (USED -Y TRACKER FOR FIRST TIME)
    - PRIME SELECT SINGLE IMU FOR STAR TRACKER PASSES DID SMOOTH DATA
  - PROXIMITY OPERATIONS
    - STATIONKEEPING AT 35 FEET ELIMINATED PLUME DISTURBANCE CONCERN. USED "NORMAL" PRCS MODE FOR TRANSLATION ADJUSTMENTS. USED "LO Z" MODE FROM 200 FEET TO 35 FEET. DID NOT USE "LO Z" FOR STATIONKEEPING
    - COUPLED DYNAMICS OF SATELLITE PLUS MMU/STINGER IS DRAMATIC, BUT EASILY ARRESTED BY MMU CONTROL SYSTEM
    - LARGE MASSES ARE RELATIVELY EASY TO HANDLE MANUALLY (UP TO 2000 LBS), HOWEVER SUFFICIENT MOTION MARGINS SHOULD BE EVALUATED IN TRAINING

1. RENDEZVOUS PROFILE IS WELL BEHAVED. THE PHASING MUST ACCOMMODATE OTHER FLIGHT PLAN ACTIVITIES AND BE WITHIN PROPELLANT BUDGETS - HENCE ALL PROFILES WILL BE CUSTOMIZED TO SOME EXTENT. MULTIPLE RENDEZVOUS CONSIDERATIONS IMPLY TRAFFIC MANAGEMENT IN FUTURE SPACE STATION/OMV/SHUTTLE OPERATIONS.

2. BAILOUT MANEUVER PLANNING IS NECESSARY. IT SHOULD BE BASED UPON PROPELLANT QUANTITIES AVAILABLE AND PROJECTED USAGE TO COMPLETE THE RENDEZVOUS SEQUENCE, ESPECIALLY ONCE THE INTERCEPT IS INITIATED. BAILOUT PLANNING IS NECESSARY FOR FUTURE RENDEZVOUS ACTIVITIES WITH ORBITER/SPACE STATION/OTHER SATELLITES/OMV.

3. IF PAYLOAD PLAYS AN ACTIVE ROLE IN PERFORMING RENDEZVOUS/PROXIMITY OPERATIONS SEQUENCE, THEN IT SHOULD CONSIDER CARRYING A RESPONSIBILITY TO PERFORM A NON-RF ACTIVATED BAILOUT MANEUVER.

4. PROPELLANT QUANTITY WILL ALWAYS BE A PREMIMUM - ORBITER FORWARD RCS IS MOST LIMITING FOR PROXIMITY OPERATIONS.

5. RENDEZVOUS OPERATIONS TO DATE HAVE ALL HAD EXCELLENT PERFORMANCE FROM NAVIGATION SENSORS, HENCE OPERATIONS APPEAR TO BE STANDARDIZED. FAILURE MODES AND DISPERSED TRAJECTORY CONDITIONS HAVE NOT YET BEEN ENCOUNTERED.

6. CREW CONTROL OF PAYLOAD ATTITUDE EASES RMS OR MMU CAPTURE TASK.

7. PROXIMITY OPERATIONS WILL TEND TO BE CUSTOM DESIGNED FOR EACH PAYLOAD. PAYLOAD FLEXIBILITY WILL GO A LONG WAY IN STABILIZING THIS AREA (E.G., RMS GRAPPLE FIXTURE, HAND HOLDS, RETRACTABLE APPENDAGES, COOPERATIVE TRACKING, ATTITUDE CONTROL CAPABILITY/MANEUVERABILITY.

8. CONTAMINATION EVALUATION IS REQUIRED FOR SPECIFIC PAYLOAD AND SPECIFIC PROXIMITY OPERATIONS TECHNIQUE.

9. PLUME DISTURBANCE SUSCEPTIBILITY OF EACH PAYLOAD MUST BE WELL UNDERSTOOD FOR PROXIMITY OPERATIONS DESIGN. IF SUSCEPTIBILITY IS SIGNIFICANT THEN ALTERNATE RECOVERY SCHEMES SHOULD BE DEVELOPED.

10. LIGHTING IS A SIGNIFICANT FACTOR IN COMPLETING A RENDEZVOUS/PROXIMITY OPERATIONS SEQUENCE. SUNLIGHT (DIRECT OR REFLECTED) CAN BLIND CREWMAN OR CAUSE TV CAMERAS TO "BLOOM" ETC. INSUFFICIENT LIGHTING REQUIRES CLOSE-IN STATIONKEEPING TO KEEP TARGET IN SIGHT DURING DARK PASSES.

11. CAUTION SHOULD BE TAKEN WHEN USING VISUAL RELATIVE MOTION CUES FOR STATION-KEEPING. UNEXPECTED TARGET MOTION (NOTABLY IN DARKNESS) MAY RESULT IN HIGHER THAN EXPECTED PROPELLANT CONSUMPTION ("SIMPLE" STATIONKEEPING CAN EASILY BECOME A FLYAROUND, ESPECIALLY IF PLUME IMPINGEMENT IS NOT WELL ANALYZED).

12. PROPELLANT RESERVES TO COVER RESCUE OF AN MMU ARE CONSIDERABLY HIGHER FOR THE THREE BODY PROBLEM (COLLISION AVOIDANCE) THAN FOR THE TWO BODY (SINGLE ROTATION FOLLOWED BY TRANSLATION AND BRAKING).

13. SINCE EACH RETRIEVABLE PAYLOAD WILL SPECIFY DIFFERENT CONTAMINATION REQUIREMENTS AND WILL OFFER A VARIETY OF PROFILES, SURFACE AREAS AND MOMENTS OF INERTIA, AND WILL BE CONTROLLED IN ATTITUDE AND TRANSLATION BY A VARIETY OF MEANS THEN CONSIDERATION SHOULD BE GIVEN TO PROVIDING A FLEXIBLE RETRIEVE INTERFACE THAT WILL ALLOW CAPTURE BY A PRIMARY AND A BACKUP METHOD. THIS APPLIES TO ORBITER, OMV AND SPACE STATION CAPTURE ACTIVITIES.

14. LARGE MASS PAYLOADS CAN BE MAN-HANDLED WITH RELATIVE EASE PROVIDED PROBLEM HAS BEEN THOUGHT THROUGH IN ADVANCE AND IF SUITABLE HANDHOLDS ARE AVAILABLE.

15. HIGH FIDELITY MAN-IN-THE-LOOP SIMULATION IS CRUCIAL IN TECHNIUQE DEVELOPMENT AND OPERATING TRAINING.

RENDEZVOUS AND PROXIMITY OPERATIONS MISSION OPERATIONS -FLIGHT DESIGN- PERSPECTIVE

KEN YOUNG, FM2
JEROME BELL, PD4
JSC
FEBRUARY 19, 1985

OUTLINE

- FLIGHT DESIGN PHASES/DEFINITIONS
- FUTURE NEEDS IN RENDEZVOUS/PROXIMITY OPERATIONS
- EXAMPLES
- CONCLUSIONS

- **RENDEZVOUS/PROXIMITY OPERATIONS FLIGHT DESIGN**
  - FOUR PHASES

PRE-FLIGHT CONCEPTUAL

- FLIGHT DESIGN IN SUPPORT OF SYSTEMS REQUIREMENTS DEFINITION
- DEFINE MISSION OBJECTIVES/REQUIREMENTS
- DEFINE TRAJECTORIES TO ACHIEVE OBJECTIVES
  - MISSION SEQUENCING
  - MANEUVER DEFINITION
  - CONSTRAINT INTEGRATION
- PERFORMANCE ANALYSIS
  - PROPELLANT BUDGETING
- DEFINE SUPPORT ELEMENT NEEDS E.G., FLIGHT SOFTWARE REQUIREMENTS TOOL AND SIMULATION DEVELOPMENT

PRE-FLIGHT OPERATIONAL

- TO INITIATE ACTUAL FLIGHT/MISSION
- PROVIDE DETAILED TRAJECTORY PLAN, SOFTWARE LOAD FLIGHT TECHNIQUES, ETC.
- PRODUCE SIMULATION, TRAINING DATA

REAL-TIME

- SUPPORT NOMINAL (PRE-PLANNED) ACTIVITY
- REACT TO CONTINGENCY SITUATIONS
- RE-PLAN ALTERNATES

POST-FLIGHT

- ASSESS SUCCESS/FAILURE
- RECOMMEND CHANGES/IMPROVEMENTS

- WHAT WE SEE AS SIGNIFICANTLY DIFFERENT ABOUT RENDEZVOUS/PROX OPS SITUATION IN THE SPACE STATION/PLATFORM ERA.

  - VARIETY OF "ACTIVE" VEHICLES (SYSTEMS)

    - SHUTTLE
    - SPACE STATION
    - PLATFORMS
    - OMV
    - OTV

  - HIGH TRAFFIC - MULTITUDE OF "SIMULTANEOUS" MISSIONS OR ACTIVITIES

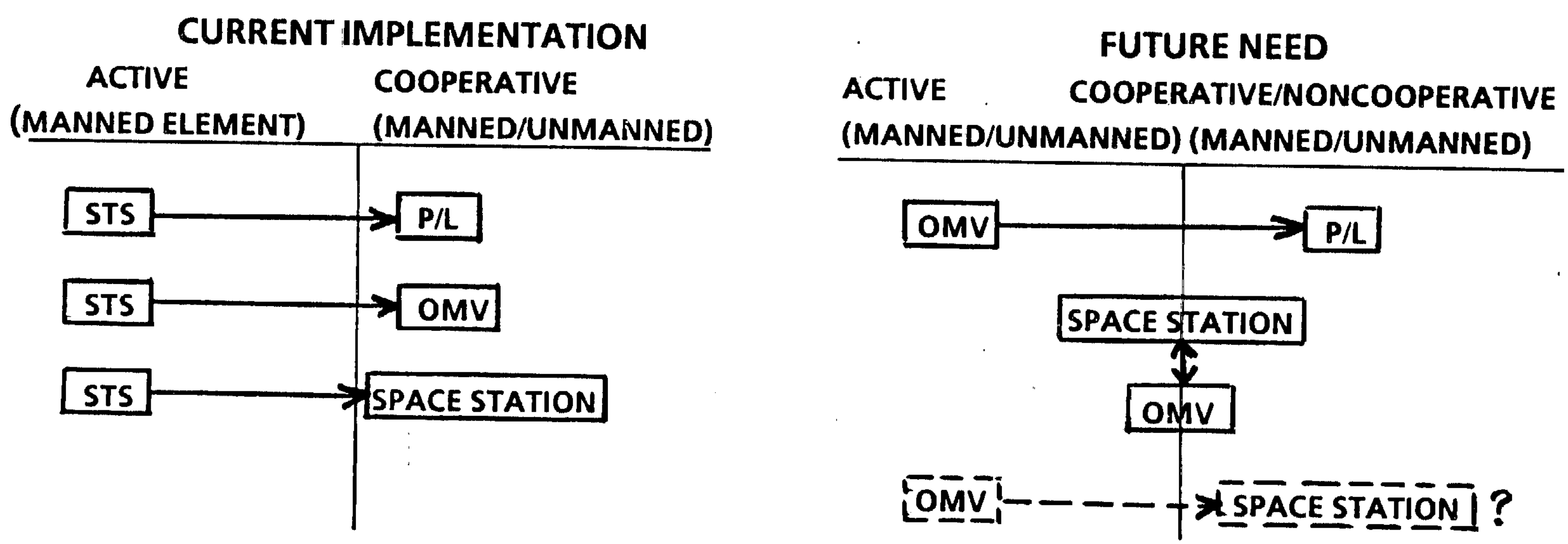
  - PRECISION CONTROL IN PROX OPS

  - REMOTE OPERATIONS - ACTIVITIES IN REGIONS "INACCESSIBLE" TO MAN

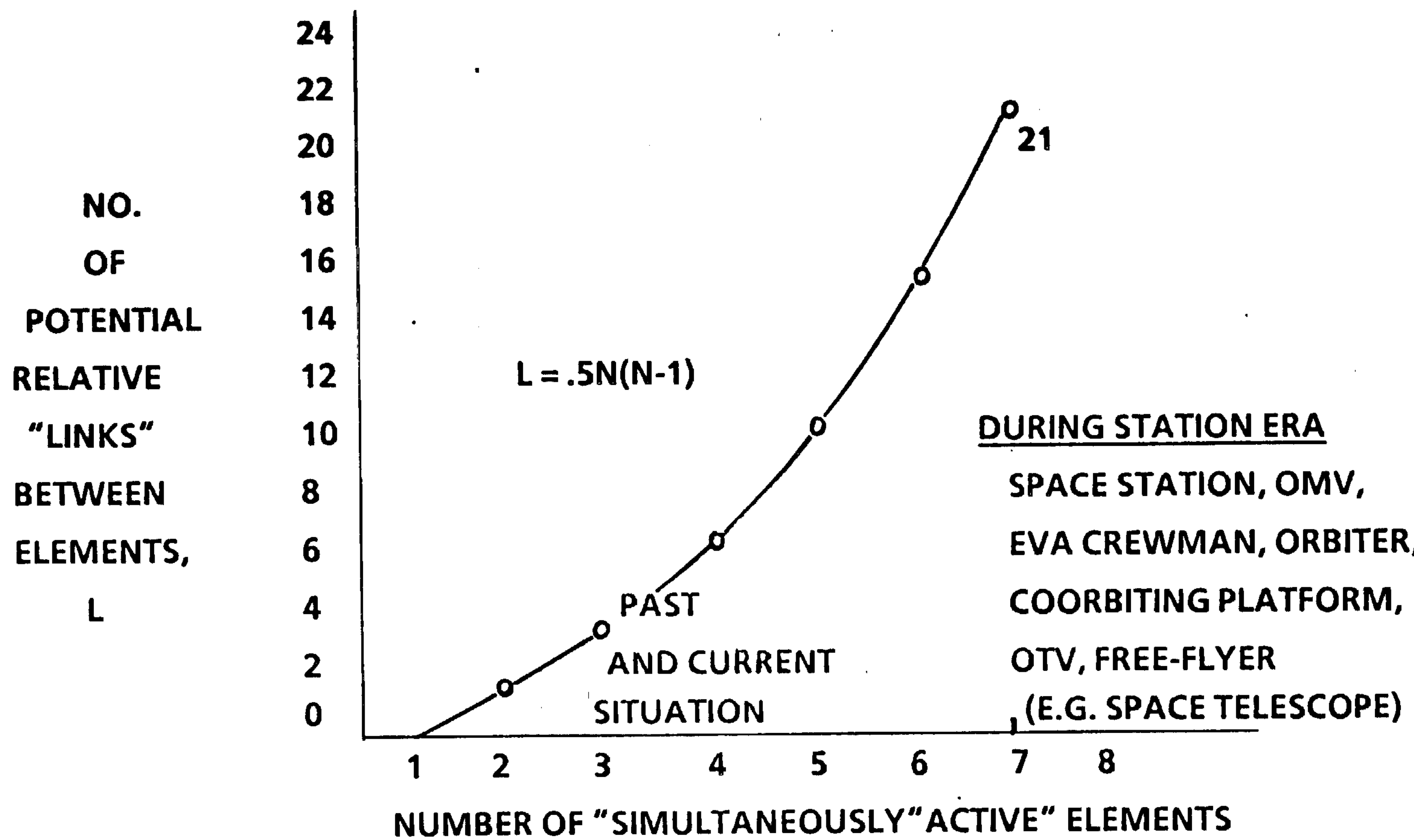
- **VARIETY OF ACTIVE SYSTEMS**
- NEED TO EVOLVE FROM A "CENTRALIZED" PROXIMITY OPERATIONS ROLE TO "DISTRIBUTED" ROLE

PROXIMITY OPERATIONS REQUIRED FUNCTIONAL CAPABILITIES

CAPABILITY	STS	OMV	SS
RELATIVE TRANSLATION	X	X	
PROX OPS COMMAND/CONTROL	X	X (GROUND)	X
UNCONSTRAINED ROTATIONAL MANEUVERING	X	X	
BERTHING/DOCKING/GRAPPLE	X	X (WITH P/L)	X



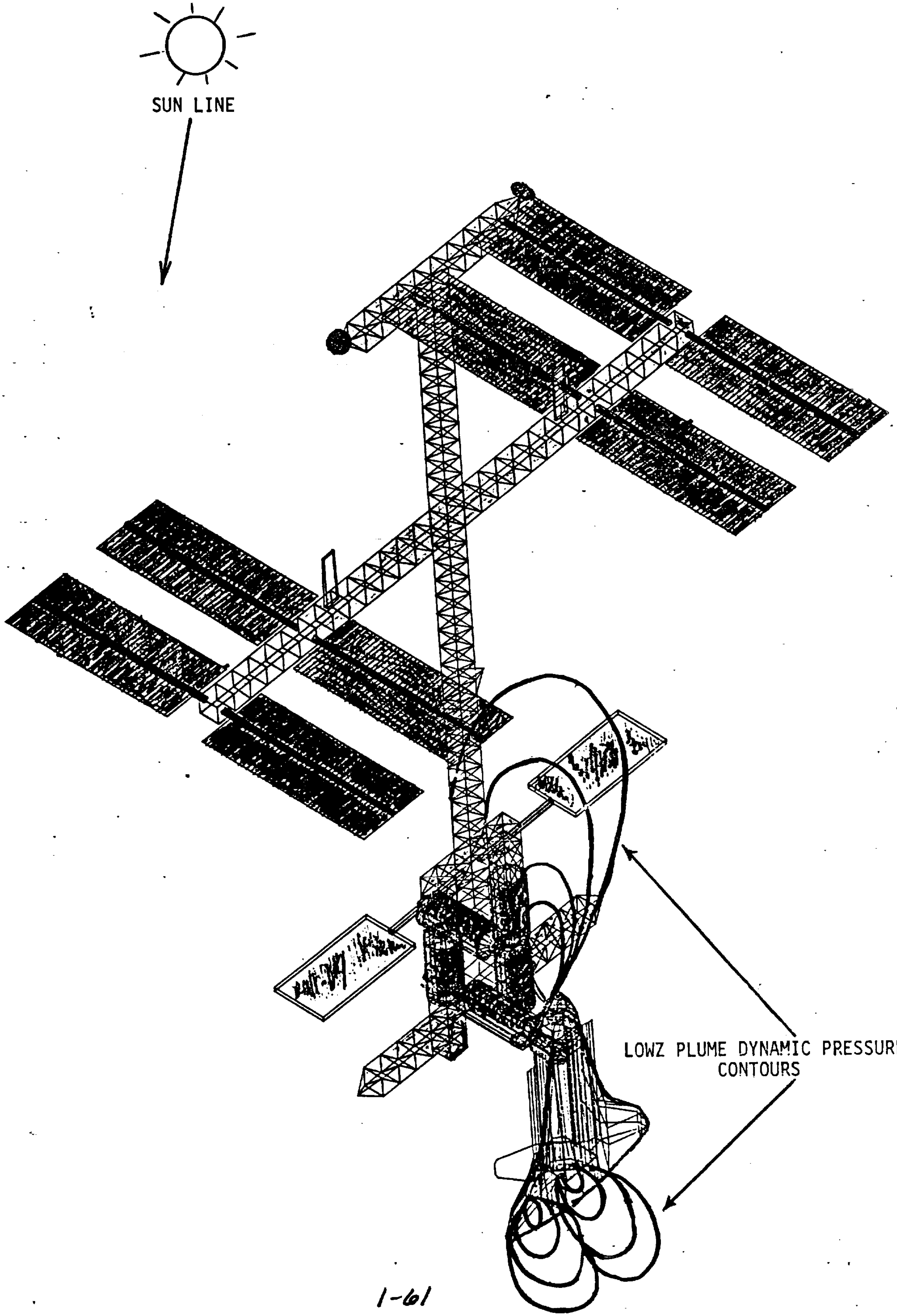
- **HIGH TRAFFIC**



- **PRECISION CONTROL**
  - FOR LARGE STRUCTURE MATING, DOCKING DYNAMICS
  - TO MINIMIZE PLUME IMPINGEMENT FOR CONTAMINATION/OVERPRESSURE REASONS

FLIGHT DESIGN IMPACT

- IN CONCEPTUAL PHASE
  - ASSESS "PROBLEM"
  - DEFINE SOLUTION IF REQUIRED
- IN OPERATIONAL AND REALTIME PHASES
  - MAY NEED PRECISION GUIDANCE/NAVIGATION CAPABILITIES
  - IF "MAN-IN-LOOP"–MUST MAINTAIN PROFICIENCY
  - PRECISION CONTROL BY OMV MAY MEAN SEPARATE "COLD GAS" VERNIER SYSTEM - COULD LIMIT PROX OPS AS FORWARD RCS DOES ON ORBITER


SUN LINE
LOWZ PLUME DYNAMIC PRESSURE
CONTOURS

- **REMOTE OPERATIONS**

  - IN-SITU SERVICING OF PLATFORMS/FREE FLYERS IS HIGHLY DESIRABLE - REDUCED " DOWNTIME"FOR PRODUCTION/SCIENCE - HUGE PERFORMANCE GAINS

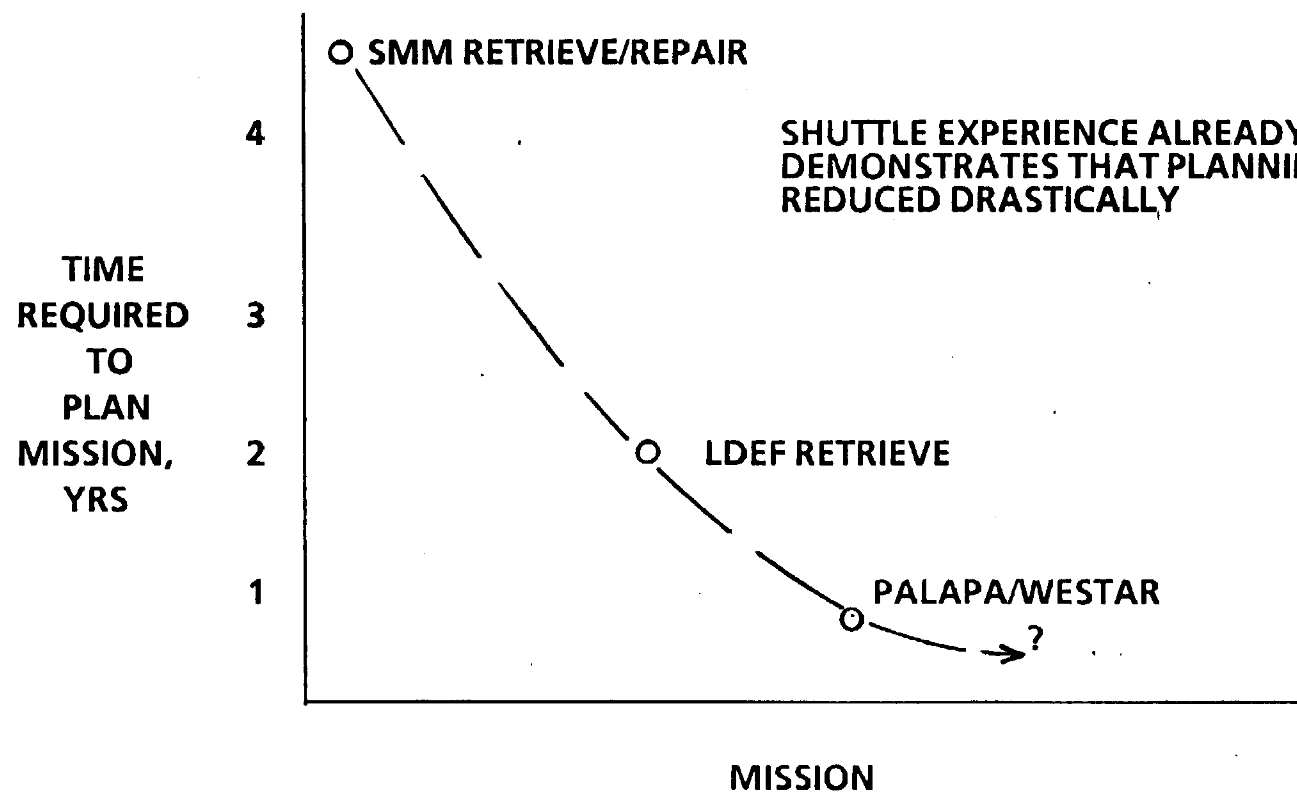
  - LOW G THRUSTING BY OMV IF IT MUST BRING P/L TO STATION/ORBITER MAY BE REQUIRED TO AVOID DISTURBANCES TO P/L (CRYSTALS, ETC>) - IMPACT ON OMV DESIGN

  - CURRENT PROJECTION IS FOR MANY SERVICING MISSIONS IN FIRST YEARS OF SPACE STATIONS/PLATFORM OPS --PROPELLANT REQUIREMENTS MAY BE STAGGERING

  - OMV "REMOTE MANUAL CONTROL" MEANS HIGHLY PROFICIENT GROUND/STATION CREW WITH REDUNDANT COMM/TV/COMMAND LINKS TO PREVENT TIME-CRITICAL CONTINGENCIES (DROP-OUTS, ETC.)

  - AUTOMATED "SMART- FRONT END OMV" MEANS SOPHISTICATED SYSTEM/COSTS - MANUAL BACKUP - TRADES MUST BE MADE

- **WHAT MUST BE DONE TO ACHIEVE SUCCESS?**
  - REDUCE PLANNING TIME BY DEVELOPMENT OF NEW TOOLS, SIMULATORS, ETC. COMPRESS PLANNING CYCLE TO MINIMIZE TENDENCY TO SUCCUMB TO PARKINSON'S LAW (WORK FILLS TIME AVAILABLE)
  - MANAGEMENT PHILOSOPHY CHANGE- DON'T INSIST ON PREFLIGHT EXAMINATION OF "EVERY" POTENTIAL SITUATION
  - STANDARDIZE TECHNIQUES/PUSH COMMONALITY OF HARDARE AND SOFTWARE



- HIGH TRAFFIC
  - DEFINE OPERATIONAL CONTROL ZONES
  - DEVELOP TRAFFIC CONTROL SYSTEM (SOFTWARE, SENSORS, COMM LINKS, AUTOMATION)
- PRECISION CONTROL
  - ANALYZE CONFIGURATIONS VS USER REQUIREMENTS AND DETERMINE NEEDED DEGREE OF PRECISION
  - DETERMINE WHETHER MAN-IN-LOOP CAN ACHIEVE NECESSARY PRECISION
    - MAY "FORCE" AUTOMATION
    - OR MAY REQUIRE TOO MUCH CREW TIME TO MAINTAIN PROFICIENCY
- REMOTE OPERATIONS
  - MUST PERFORM IN-DEPTH COST TRADES ON IN-SITU SERVICING VS. STATION/SHUTTLE SERVICING
  - PROPELLANT SAVINGS/LESS RENDEZVOUS PLANNING/LESS CREW INVOLVEMENT FAVORS IN-SITU BUT COST OF AUTOMATION, ROBOTICS, AND CONTINGENCY SOLUTIONS MAY BE EVEN "GREATER"
  - THERE MAY BE DEGREES OF IN-SITU SERVICING, I.E. SOME IN-SITU MISSIONS LIKE "SIMPLE" CRYO REFUELING - OTHERS SUCH AS INSTRUMENT CHANGEOUT MAY BE TOO COMPLEX FOR ROBOTICS - THESE MUST BE BROUGHT TO STATION/ORBITER

CONCLUSIONS/FOOD FOR THOUGHT

- SEVERAL "NEW" ASPECTS OF RENDEZVOUS/PROX OPS IN THE STATION ERA MUST BE CAREFULLY ASSESSED
- COMMUNITY SHOULD ESTABLISH STRONG GOALS TOWARD STANDARDIZATION AND COMMONALITY
- LONG TERM OBJECTIVES (IN-SITU, PLANETARY) LEND ARGUMENT TO STRIVE TOWARD OMV AUTOMATED RENDEZVOUS/PROX OPS WITH MANUAL CONTROL AS BACK-UP
- STRIVE TOWARD REDUCTION IN "MAN-IN-LOOP" INVOLVEMENT SO CREW TRAINING/PROFICIENCY MAINTENANCE CAN DECREASE
- FLIGHT DESIGN/PLANNING FUNCTIONS MUST BE WISELY PARTITIONED BETWEEN GROUND AND STATION- MAY BE OVER EMPHASIS ON STATION AUTONOMY E.G., WITH RESPECT TO OMV RENDEZVOUS PLANNING - PARTITIONING MAY JUST HAVE TO EVOLVE

27 MARCH 1985

SESSION 2 - USER REQUIREMENTS PLENARY SESSION

2-1. "RENDEZVOUS AND PROXIMITY OPERATIONS DURING EURECA MISSIONS" - ECKART GRAF/EUROPEAN SPACE AGENCY, ESTEC

2-2. "SPARTAN RENDEZVOUS" - SCOTT LAMBROS AND JOSEPH KING/NASA GSFC

2-3. "DYNAMICS OF SOLAR MAXIMUM MISSION SPACECRAFT CAPTURE AND REDEPLOYMENT ON STS-41C" - KEVIN GRADY/NASA GSFC

2-4. "LEASECRAFT/MATERIALS PROCESSING - RENDEZVOUS, PROXIMITY OPERATIONS AND COST TRADEOFFS" - R. O'BRIEN/FAIRCHILD SPACE COMPANY

2-5. "SPACE TELESCOPE" - THOMAS STYCZYNSKI/LOCKHEED MISSILES AND SPACE COMPANY

2-6. "ADVANCED X-RAY ASTROPHYSCIAL FACILITY - SERVICING CONCEPTS" - JAMES STEINCAMP/NASA MSFC

2-7. "CONTAMINATION EFFECTS DURING RENDEZVOUS AND PROXIMITY OPERATIONS" - EDGAR MILLER/NASA MSFC, JOHN ALRED AND LUBERT LEGER/NASA JSC.

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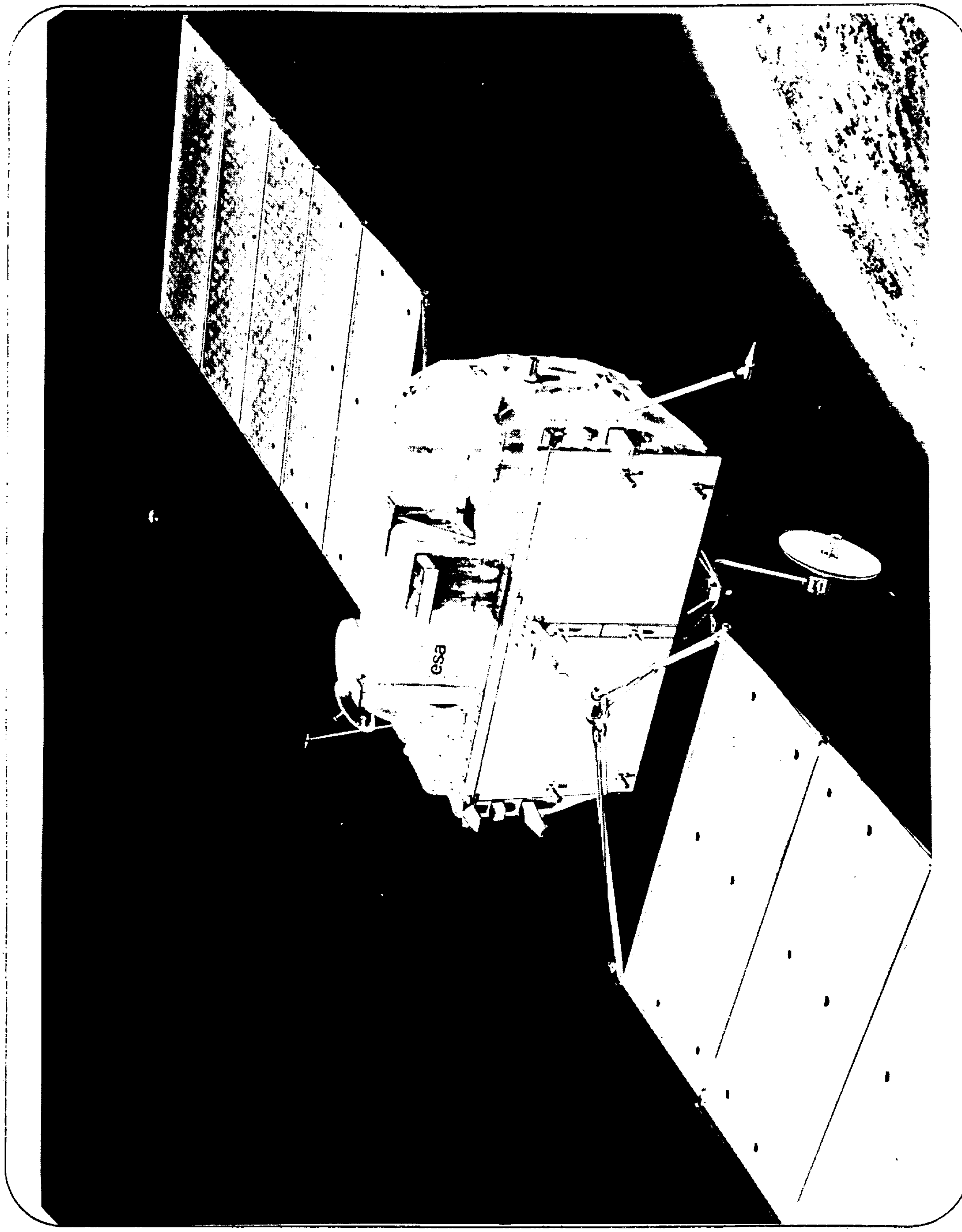
EURECA

RENDEZ-VOUS AND PROXIMITY OPERATIONS

ECKART D. GRAF
EUROPEAN SPACE AGENCY
ESTEC, NOORDWIJK, THE NETHERLANDS.

RENDEZ-VOUS AND PROXIMITY
OPERATIONS WORKSHOP
HOUSTON, February 19-22, 1985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EURECA

EUropean REtrievable CArrier

RENDEZ-VOUS AND PROXIMITY OPERATIONS DURING EURECA MISSIONS

ABSTRACT

EURECA, THE EUROPEAN RETRIEVABLE CARRIER, WILL USE THE STS FOR DEPLOYMENT AND RETRIEVAL SERVICES. WHILE EURECA's OPERATIONAL ORBITAL ALTITUDE WILL BE AROUND 270 N MI, IT WILL BE DEPLOYED/RETRIEVED IN THE STANDARD STS ORBITS OF 160 N MI/170 N MI, RESPECTIVELY. FOR RETRIEVAL THIS REQUIRES ORBITAL TRAJECTORY MANOEUVRING OF BOTH VEHICLES : EURECA WILL FIRST HAVE TO MEET A SPECIFIED TARGET POINT (RENDEZ-VOUS CONTROL BOX), THE ORBITER WILL PERFORM RENDEZ-VOUS AND PROXIMITY OPERATIONS WITH EURECA AS A PASSIVE TARGET DURING FINAL APPROACH.

THIS PAPER DESCRIBES RENDEZ-VOUS AND PROXIMITY OPERATION TIME-LINES AND ACTIVITIES REQUIRED IN SUPPORT OF EURECA DEPLOYMENT/RETRIEVAL MISSIONS AS WELL AS PROVIDES CONCEPTS AND REQUIREMENTS FOR FUTURE EURECA/SPACE STATION MISSIONS WITH EMPHASIS ON THE DIVISION OF RESPONSIBILITY BETWEEN THE USER AND THE STS AND/OR SPACE STATION.

CONTENT

EURECA
EUropean REtrievable CArrier

- EURECA PROGRAMME SUMMARY
- MISSION-I CHARACTERISTICS (MICROGRAVITY, SCIENCE, TECHNOLOGY)
- FUTURE MISSIONS (SOLAR PHYSICS, ASTRONOMY, EARTH OBSERVATION, TECHNOLOGY)
- RENDEZ-VOUS AND PROXIMITY OPERATIONS DURING EURECA-I MISSION
  - DEPLOYMENT/SEPARATION
  - RETRIEVAL TECHNICAL SPECIFICATIONS
  - DIVISION OF RESPONSIBILITIES
  - PROXIMITY OPERATION ISSUES
  - RECOMMENDED IMPROVEMENTS
- RENDEZ-VOUS AND PROXIMITY OPERATIONS FOR SPACE STATION/EURECA PLATFORM OPERATION
  - COMPATIBILITY OF EURECA WITH FUNCTIONAL REQUIREMENTS
  - CANDIDATE CONCEPTS FOR SPACE STATION PROX OPS AND TRAFFIC ZONES
  - COST EFFECTIVE DIVISION OF SS/USER RESPONSIBILITIES
  - EURECA FOR EARLY INFLIGHT DEMONSTRATION OF FUTURE DESIGN AND OPERATIONAL CAPABILITIES.

EURECA PROGRAMME SUMMARY

EURECA
EUropean REtrievable CArrier

THE EUREOPEAN RETRIEVABLE CARRIER (EURECA) IS A FREE-FLYING REUSABLE PLATFORM LAUNCHED AND RETRIEVED BY THE STS. AS AN ELEMENT OF THE SPACELAB FOLLOW-ON DEVELOPMENT PROGRAMME EURECA PROVIDES TO THE USER COMMUNITY A PLATFORM WITH CAPABILITIES BEYOND THOSE OF SPACELAB REGARDING ON-ORBIT STAYTINE AND MICROGRAVITY ENVIRONMENT AND WILL ALLOW IMPORTANT RESERACH AND APPLICATION MISSIONS PRIOR TO AS WELL AS COMPLEMENTARY TO THE SPACE STATION FOR PAYLOADS WHICH DO NOT REQUIRE MAN'S INVOLVEMENT.

WHILE THE FIRST EURECA MISSION WILL BE PRIMARILY A MICROGRAVITY MISSION, THE COST-EFFECTIVENESS OF AN AVAILABLE RETRIEVABLE PLATFORM IS ALSO OF INTEREST FOR THE SPACE SCIENCE COMMUNITY, PARTICULARLY ASTRONOMY AND SOLAR PHYSICS, AND ALLOWS FLIGHT OPPORTUNITIES FOR A VARIETY OF EARTH OBSERVATION PAYLOADS. IN ADDITION, EURECA CONSTITUTES AN IDEAL TEST BED FOR IN ORBIT DEMONSTRATION OF TECHNOLOGIES LIKE INTER-ORBIT COMMUNICATION, RENDEZ-VOUS AND DOCKING, IN-ORBIT SERVICING, WHICH ARE ESSENTIAL FOR EUROPE TO ACHIEVE ITS LONG TERM OBJECTIVES IN SPACE

CONSISTENT WITH THE INITIAL OBJECTIVES OF THE EURECA PROGRAMME TO GRADUALLY EXPAND EUROPE's CAPABILITY AND COMPETITIVENESS IN THE DEVELOPMENT, UTILIZATION, AND OPERATION OF LOW EARTH ORBITING PLATFORMS, EURECA ALSO PROVIDES THE ESSENTIAL BASIS FOR TECHNOLOGIES AND OPERATIONAL CAPABILITIES REQUIRED FOR SEVERAL CANDIDATE ELEMENTS WITHIN THE EUREOPEAN SPACE STATION SCENARIO:

FOR EURECA AS A CO-ORBITING AND NON CO-ORBITING SPACE STATION PLATFORM IMPORTANT FEATURES OF THE BASELINE ARE DIRECTLY APPLICABLE AND WILL HAVE BEEN DEMONSTRATED AND QUALIFIED DURING THE FIRST MISSION, LIKE ORBIT CHANGE CAPABILITY, RENDEZ-VOUS WITH A TARGET POINT IN ORBIT IN SUPPORT OF RETRIEVAL BY THE ORBITER, ACTIVATION/DEACTIVATION OF EURECA INCLUDING SAFETY CRITICAL OPERATIONS IN ORBITER PROXIMITY, EUROPEAN MISSION AND PAYLOAD CONTROL, GROUND OPERATIONS AND LOGISTICS FOR RETRIEVABLE, REUSABLE PLATFORMS.

EURECA PROGRAMME SUMMARY (CONT'D)

EURECA
European REtrievable CArrier

EURECA CONSTITUTES THE NUCLEUS OF A RESOURCE MODULE, THE PERFORMANCE OF WHICH CAN BE ADAPTED TO COVER EVOLVING USER REQUIREMENTS IN A SMOOTH AND LOW COST PROGRAMME EVOLUTION. THE CAPABILITY OF IN-ORBIT SERVICING OF SUBSYSTEMS AND PAYLOADS CAN BE IMPLEMENTED GRADUALLY IN CORRECT PHASING WITH REALISTIC EUROPEAN MISSION REQUIREMENTS AND EVOLVING SPACE STATION ARCHITECTURES, INTERFACES AND ECONOMICS.

SERVICING FUNCTIONS OF EURECA COULD BE INTEGRATED AND APPROPRIATELY EXPANDED INTO A SERVICING VEHICLE FOR TRANSFER OF PAYLOAD, SUBSYSTEM EQUIPMENT, AND CONSUMABLES BETWEEN THE STS OR SPACE STATION AND A EUROPEAN PLATFORM.

EURECA IS AN APPROVED PROGRAMME OF THE EUROPEAN SPACE AGENCY. THE PHASE C/D STARTED IN DECEMBER 1984. PLANNED LAUNCH DATES FOR THE FIRST MISSION ARE MARCH 1988 AND SEPTEMBER 1988 FOR DEPLOYMENT AND RETRIEVAL, RESPECTIVELY.

EUREKA logo text:

EURECA PROGRAM OBJECTIVES

EURECA
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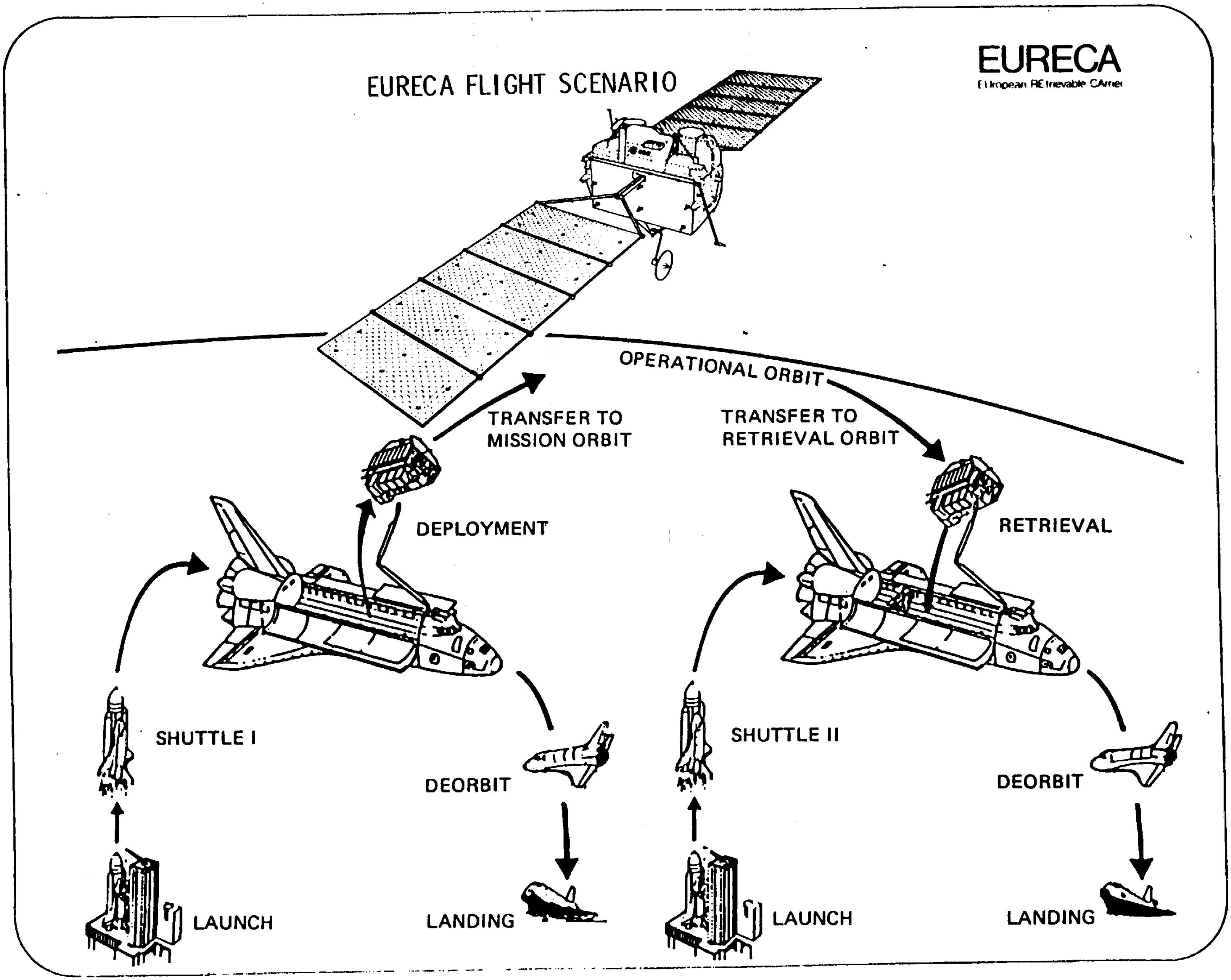
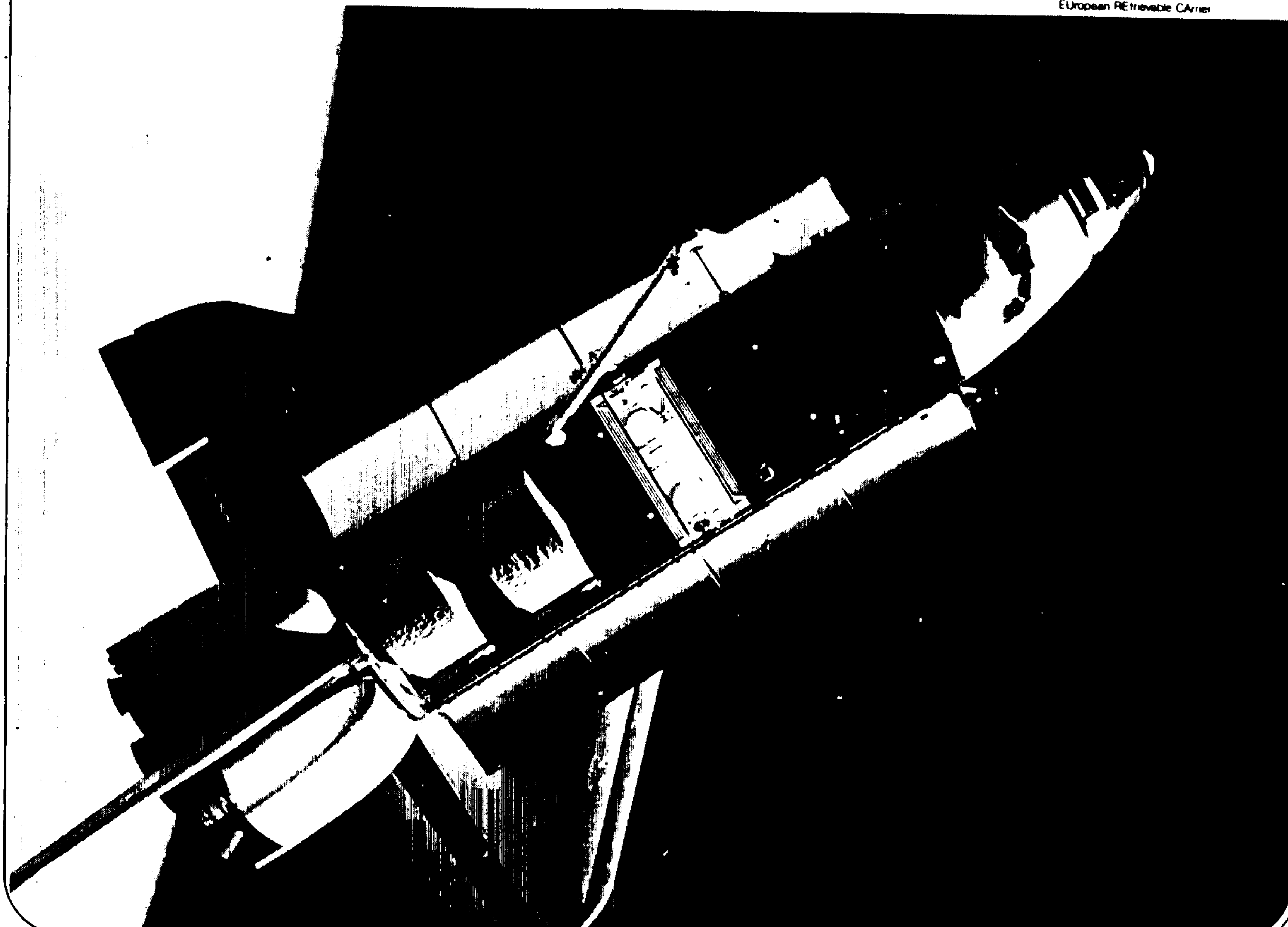
- MEET EUROPEAN PLATFORM USER REQUIREMENTS FOR MICROGRAVITY, SPACE SCIENCE, EARTH OBSERVATION, TECHNOLOGY.
- DEVELOP EUROPEAN CAPABILITIES IN SPACE PLATFORM DESIGN, DEVELOPMENT, UTILIZATION, AND OPERATION.
- ESTABLISH A CONCEPT OF REUSABLE, RETRIEVABLE PLATFORMS WHICH CAN BE ADAPTED TO MEET EVOLVING MISSION REQUIREMENTS
- DEVELOP AN INITIAL PLATFORM WHICH MEETS ESSENTIAL DESIGN, OPERATIONAL AND PROGRAMMATIC REQUIREMENTS OF FUTURE SPACE STATION ELEMENTS.

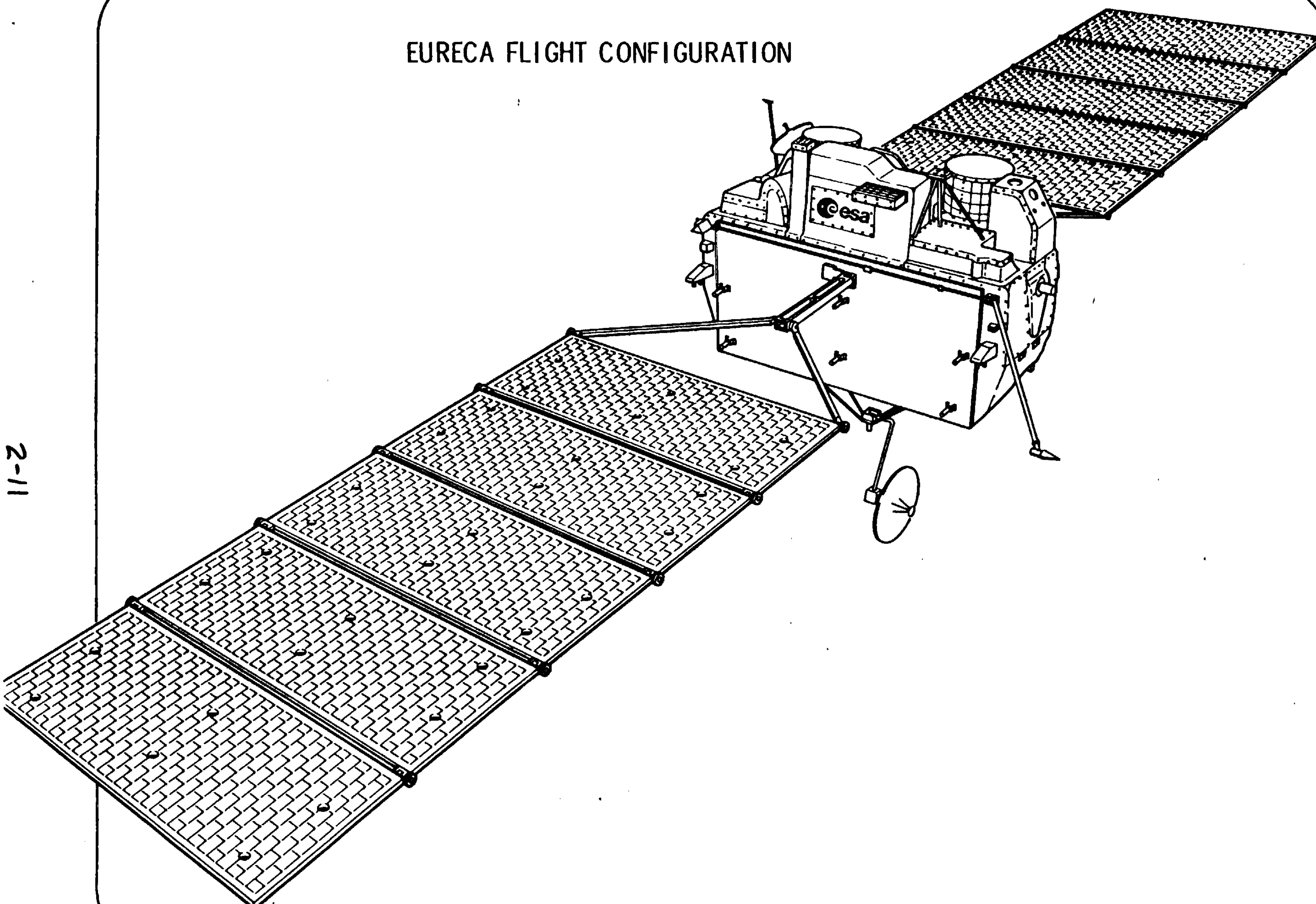

EURECA FLIGHT SCENARIO
EURECA
EUropean REtrievable CArrier
OPERATIONAL ORBIT
TRANSFER TO
MISSION ORBIT
TRANSFER TO
RETRIEVAL ORBIT
DEPLOYMENT
RETRIEVAL
SHUTTLE I
SHUTTLE II
DEORBIT
DEORBIT
LAUNCH
LANDING
LAUNCH
LANDING

EURECA IN THE ORBITER CARGO BAY

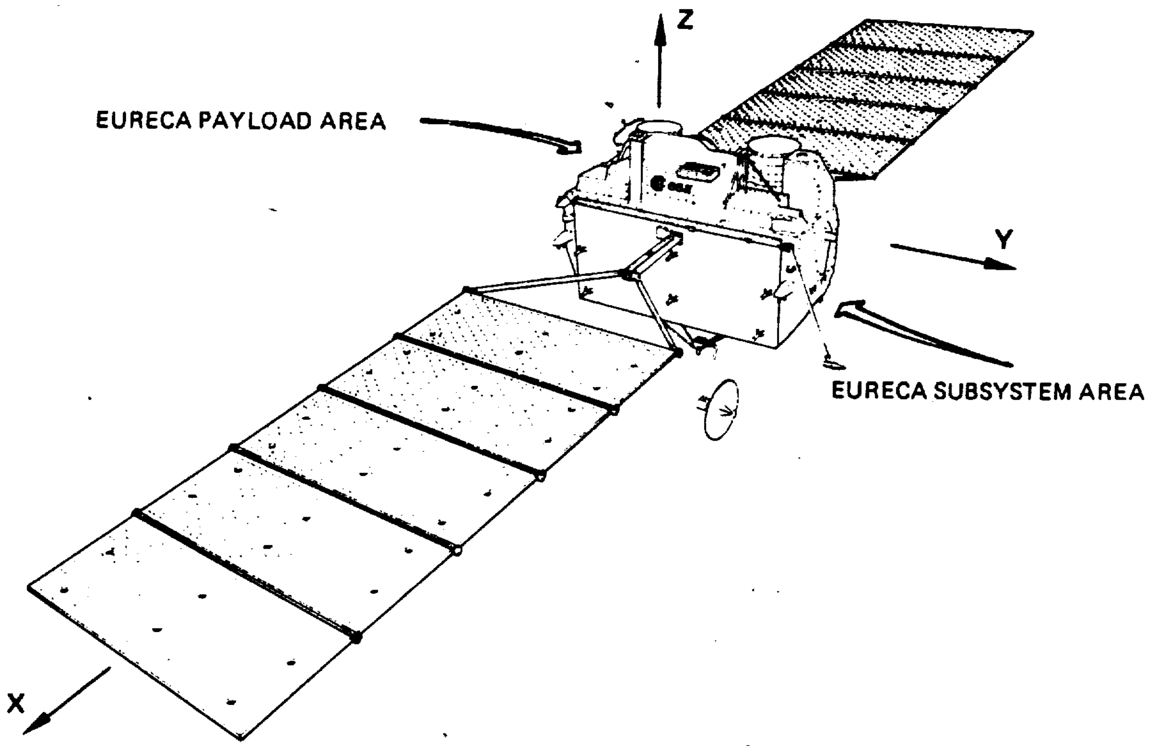
EURECA
EUropean REtrievable CArrier



EURECA FLIGHT CONFIGURATION



EURECA SYSTEM CAPABILITIES



MASS : TOTAL : 4000 kg
AVAILABLE TO PAYLOAD : 1000 kg

VOLUME : AVAILABLE TO PAYLOAD : 8,5 m^3

POWER : AVAILABLE TO PAYLOAD : 1000 W
PEAK. : 1500 W
SOLAR ARRAY OUTPUT : 5000 W

THERMAL CONTROL : LIQUID FREON LOOP (1000 W) AND MULTI LAYER INSULATION

DATA MANAGEMENT : HIGH SPEED : 256 kbps
LOW SPEED : 2 kbps DOWN LINK (S-BAND)
MEMORY CAPACITY : 128 Mbits
AVERAGE P/L : 1,5 kbps

ATTITUDE POINTING ACCURACY : ± 1° (3 SIGMA)

MICROGRAVITY : 10^{-5} g < 1 Hz
10^{-3} g > 100 Hz

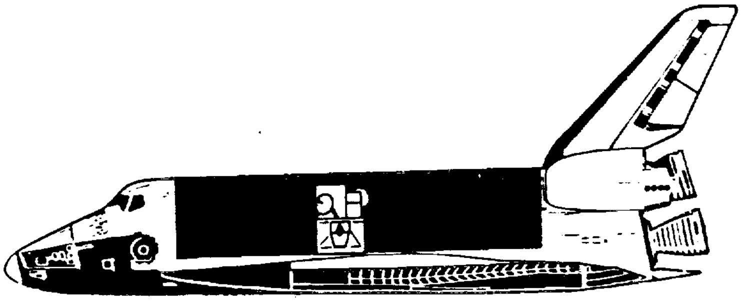
ORBIT : 525 km ; 28.5°

MISSION DURATION : 6 MONTHS OPERATIONAL + 3 MONTHS DORMANT
DESIGN LIFE : 5 MISSIONS OR 10 YEARS

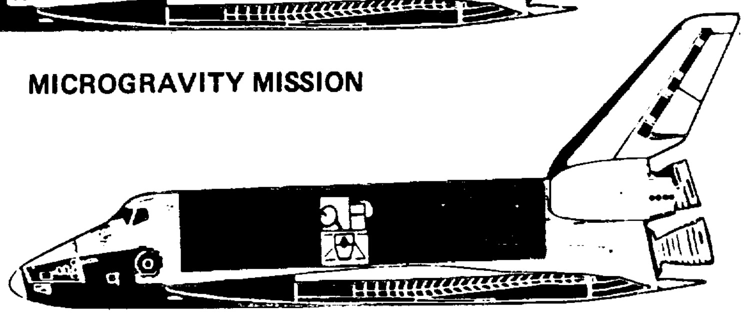
TURN AROUND TIME :
BASELINE : < 1,5 YEARS BETWEEN RETRIEVAL AND NEXT LAUNCH. REDUCTION DOWN TO LESS THAN ONE YEAR UNDER STUDY

EURECA

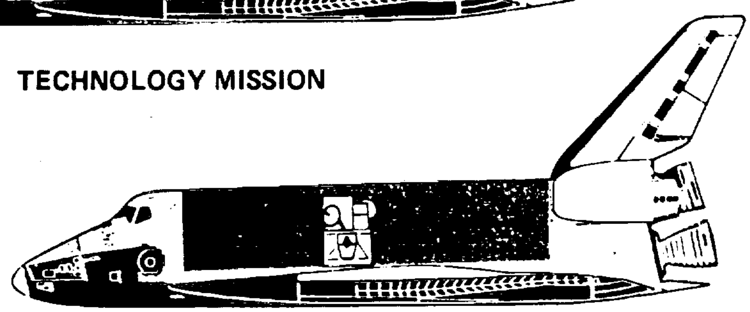
EURECA MISSIONS



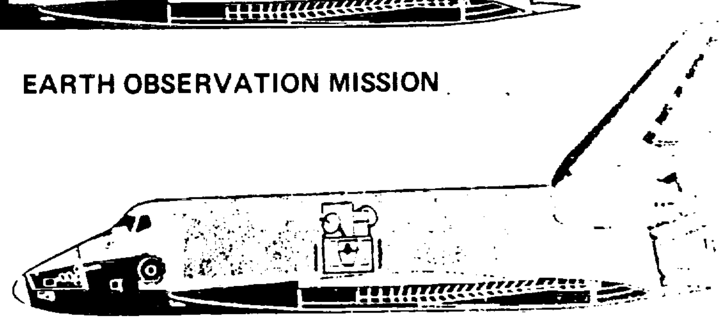
MICROGRAVITY MISSION



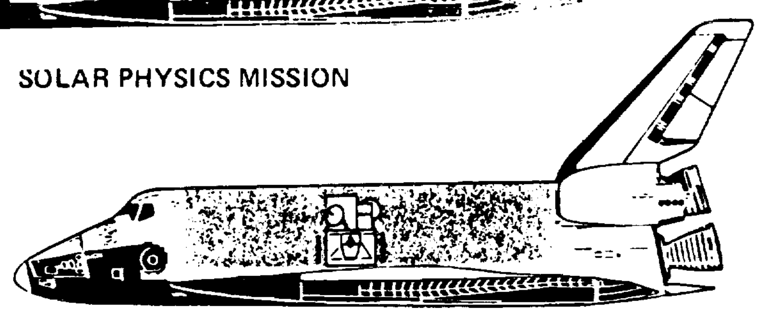
TECHNOLOGY MISSION



EARTH OBSERVATION MISSION



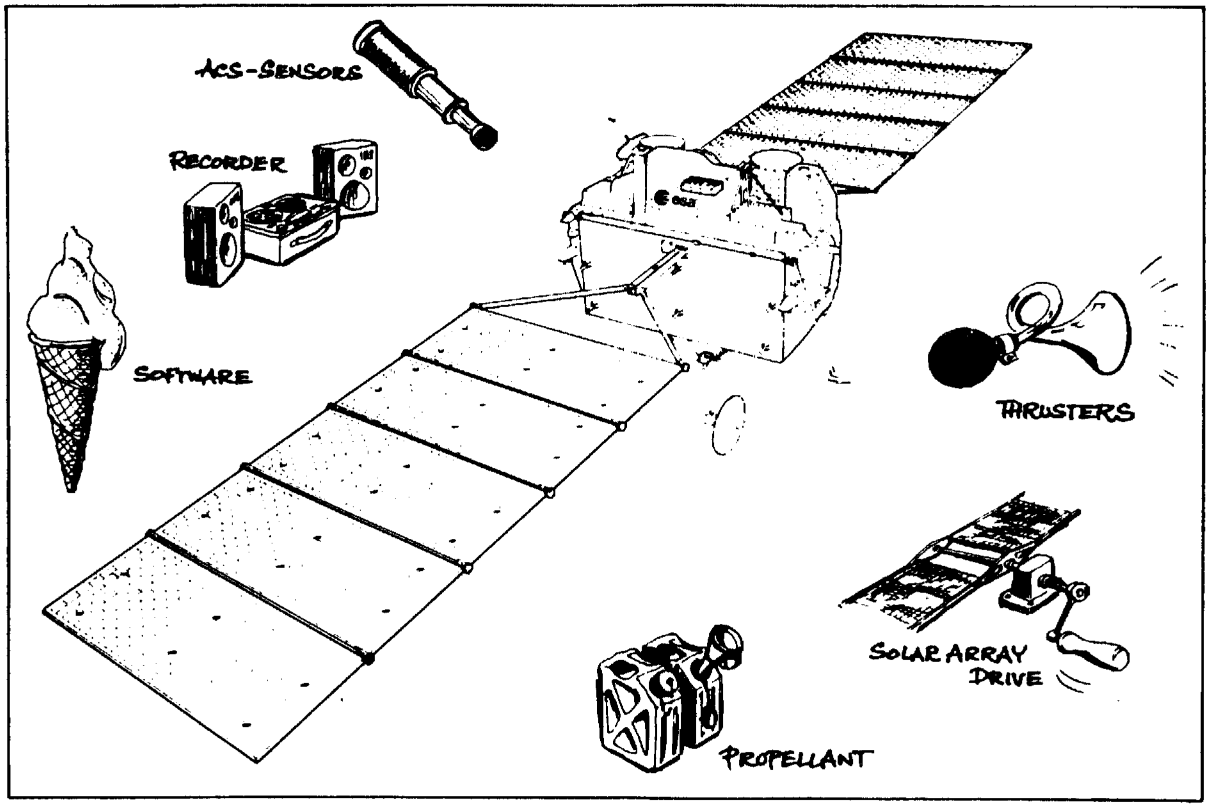
SOLAR PHYSICS MISSION



ASTRONOMY MISSION

CONCEPT FOR ADAPTATION OF EURECA

EURECA
EUropean REtrievable CArrier



EURECA CONFIGURATION FOR ASTRONOMY MISSIONS

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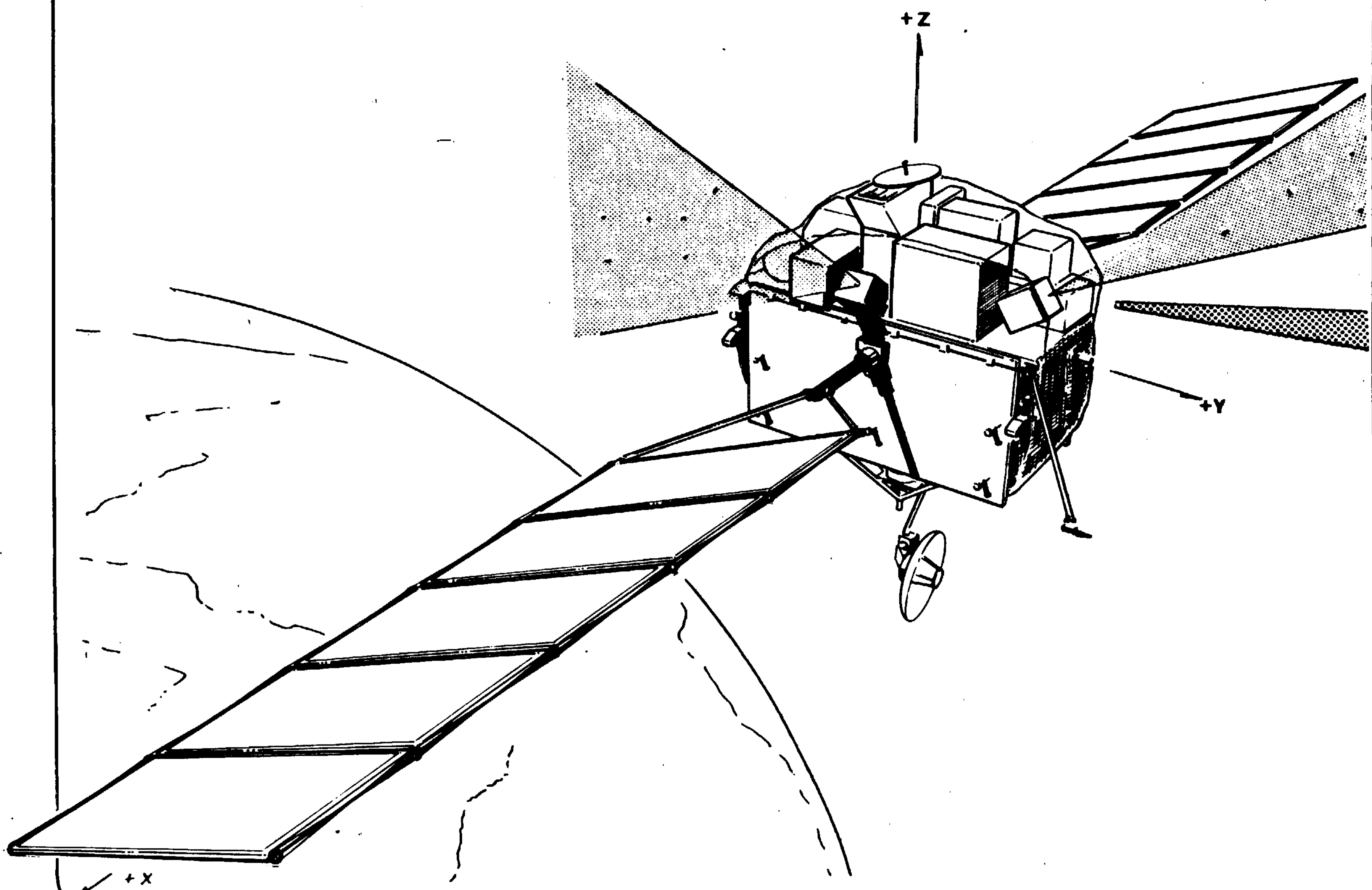
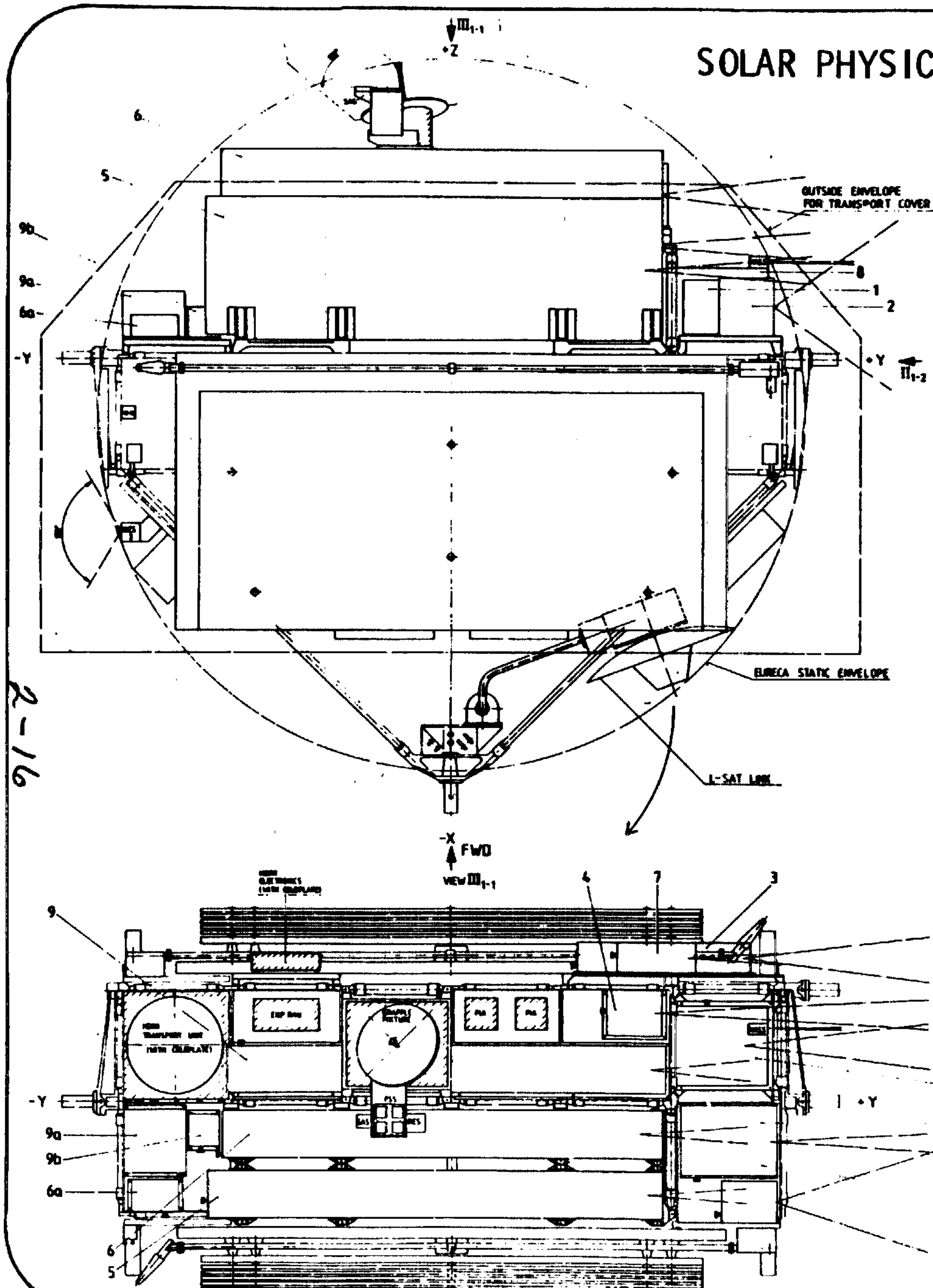
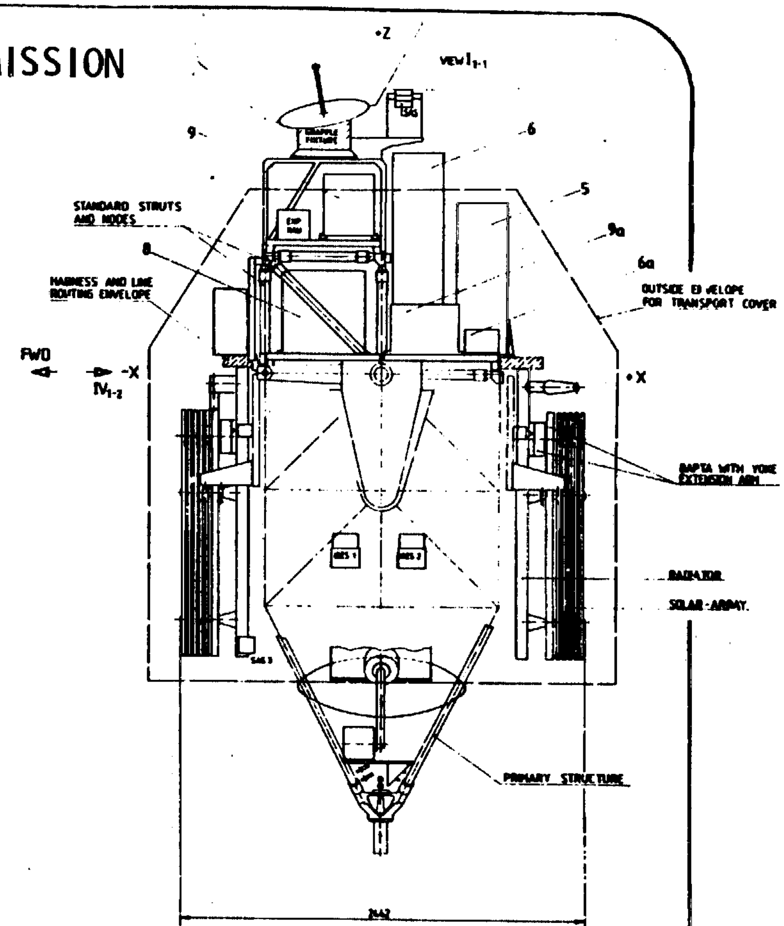
EUropean REtrievable CArrier



SOLAR PHYSICS MISSION



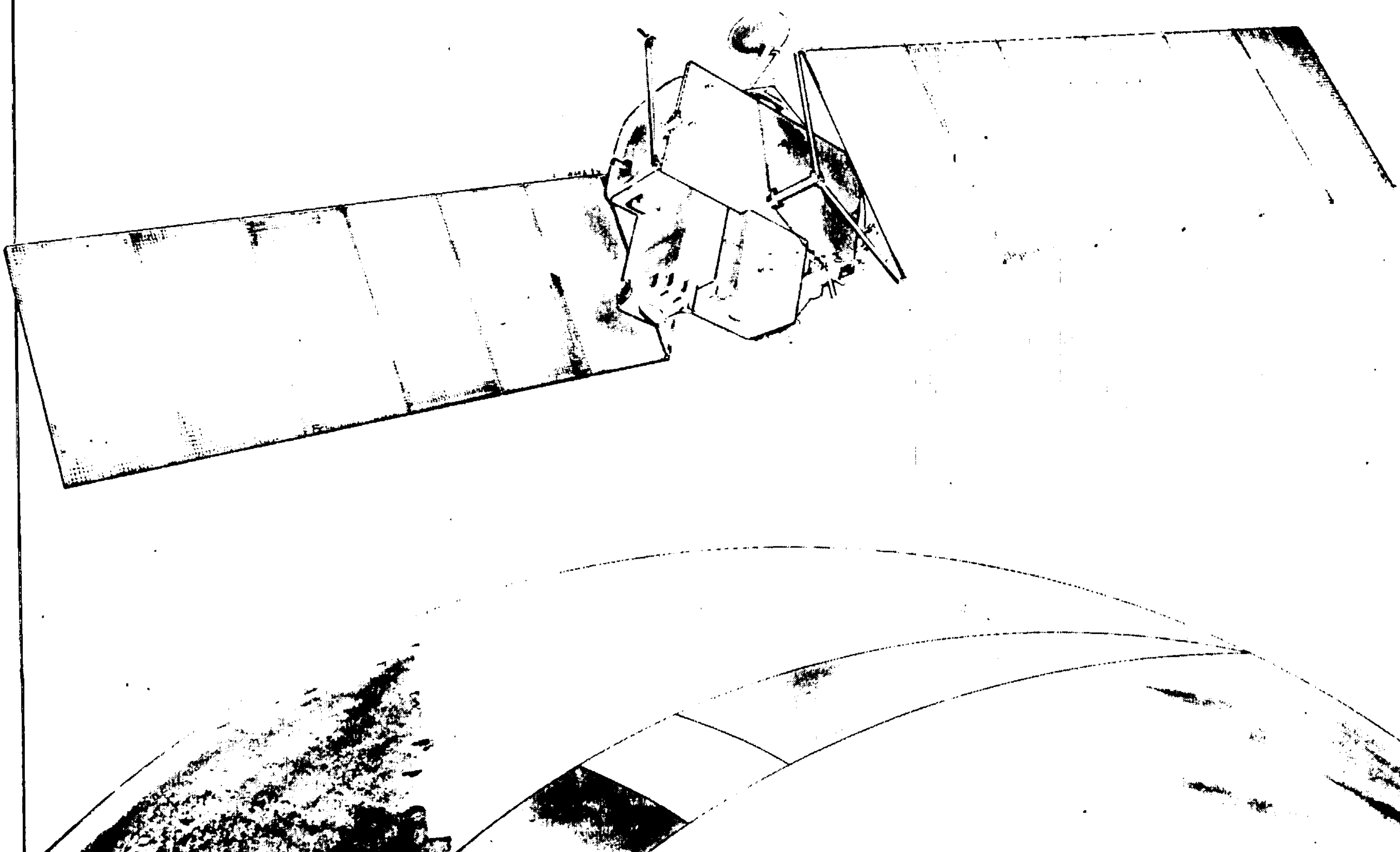


▲ HARNESS-CONN

UNIT	NAME
1	SOLAR SPECTRUM 170-300 nm
2	SOLAR CONSTANT VARIABILITY
3	IMAGING LUMINOSITY OSCILLATION
4	UV-SPECTROMETER
5	GRAZING INCIDENCE SPECTROMETER
6	NORMAL INCIDENCE SPECTROMETER
6a	" " " (ELECTRONICS)
7	EUV-IMAGING TELESCOPES
8	UV-CORONAL SPECTROMETER
9	WHITE LIGHT CORONAGRAPH
9a	" " " (ELECTRONICS)
9b	" " " "

EURECA CONFIGURATION FOR EARTH OBSERVATION MISSIONS (EO IV)

EURECA
EUropean REtrievable CArrier



EURECA FUNCTIONS IN SUPPORT OF RENDEZ-VOUS AND PROXIMITY OPERATIONS.

EURECA
EUropean REtrievable CArrier

- PROPULSION
  - TRANSFER FROM THE BASELINE ORBIT OF THE STS ORBITER OR THE SPACE STATION TO THE PLATFORM OPERATIONAL ORBIT AND RETURN FOR RENDEZ-VOUS IN THE PROXIMITY OF THE ORBITER OR THE SPACE STATION.
  - MAINTENANCE OF THE PLATFORM OPERATIONAL ORBIT
  - PROVIDE TORQUE CAPABILITY ABOUT THREE ORTHOGONAL BODY AXES FOR BACK-UP REACTION CONTROL FOR THE GN&C SUBSYSTEM
  - HARDWARE IMPLEMENTATION BY INTEGRATED HYDRAZINE PROPULSION MODULE (TANKS, THRUSTERS, LINES) AND A COLD GAS SYSTEM FOR ATTITUDE HOLD IN CLOSE PROXIMITY AND DURING MICRO-GRAVITY OPERATIONS.

EURECA BASELINE MISSION PROFILE

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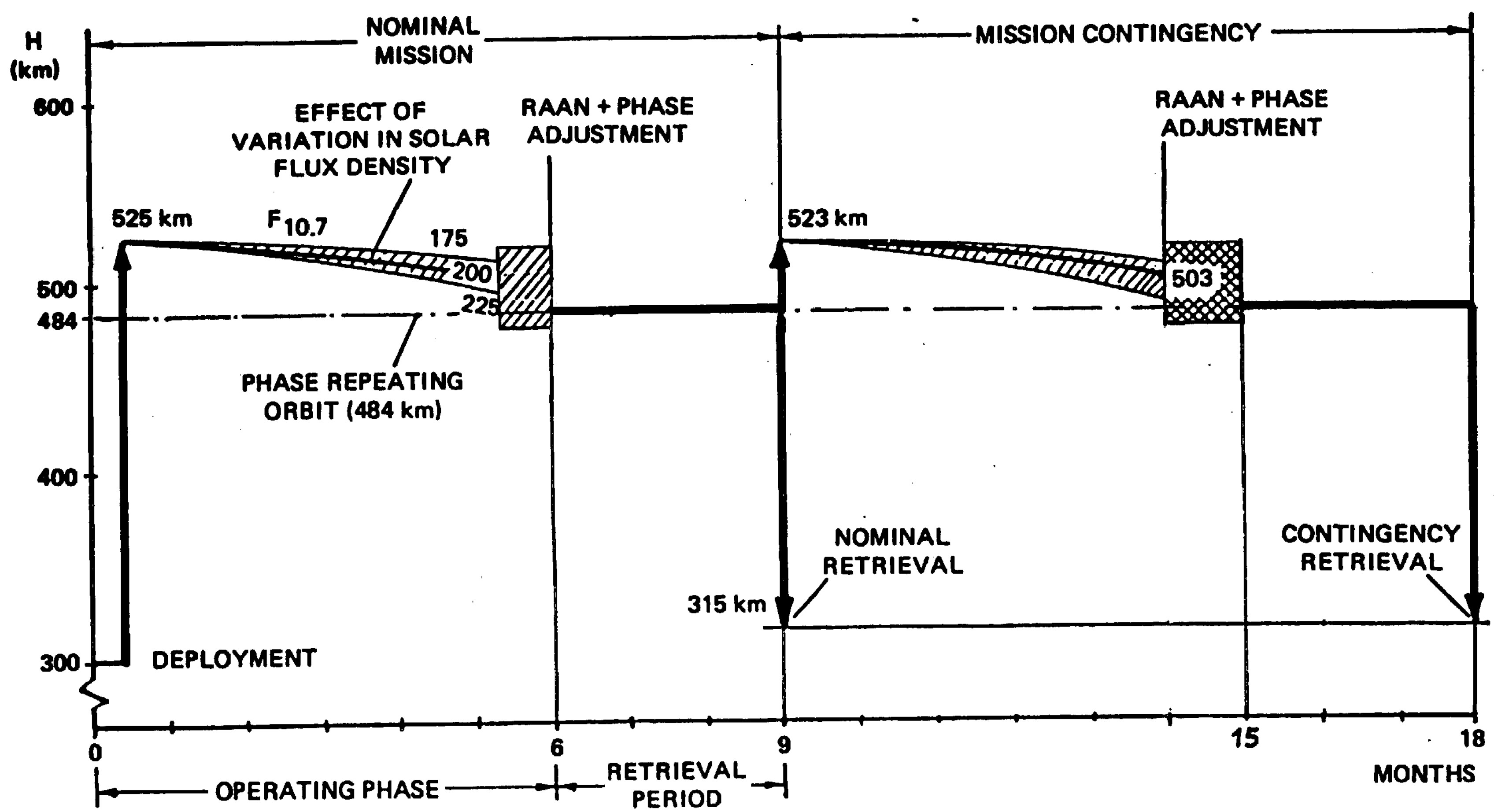
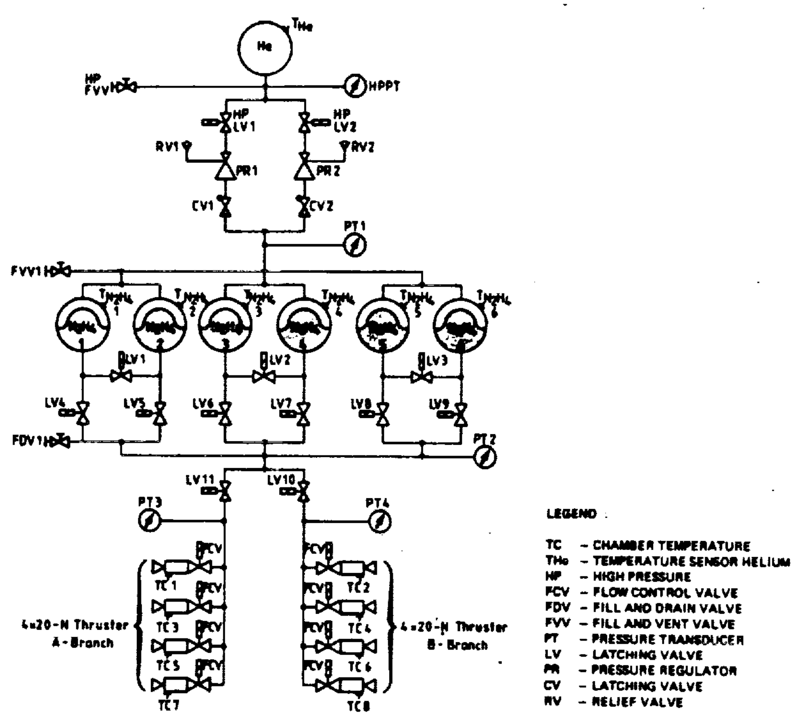
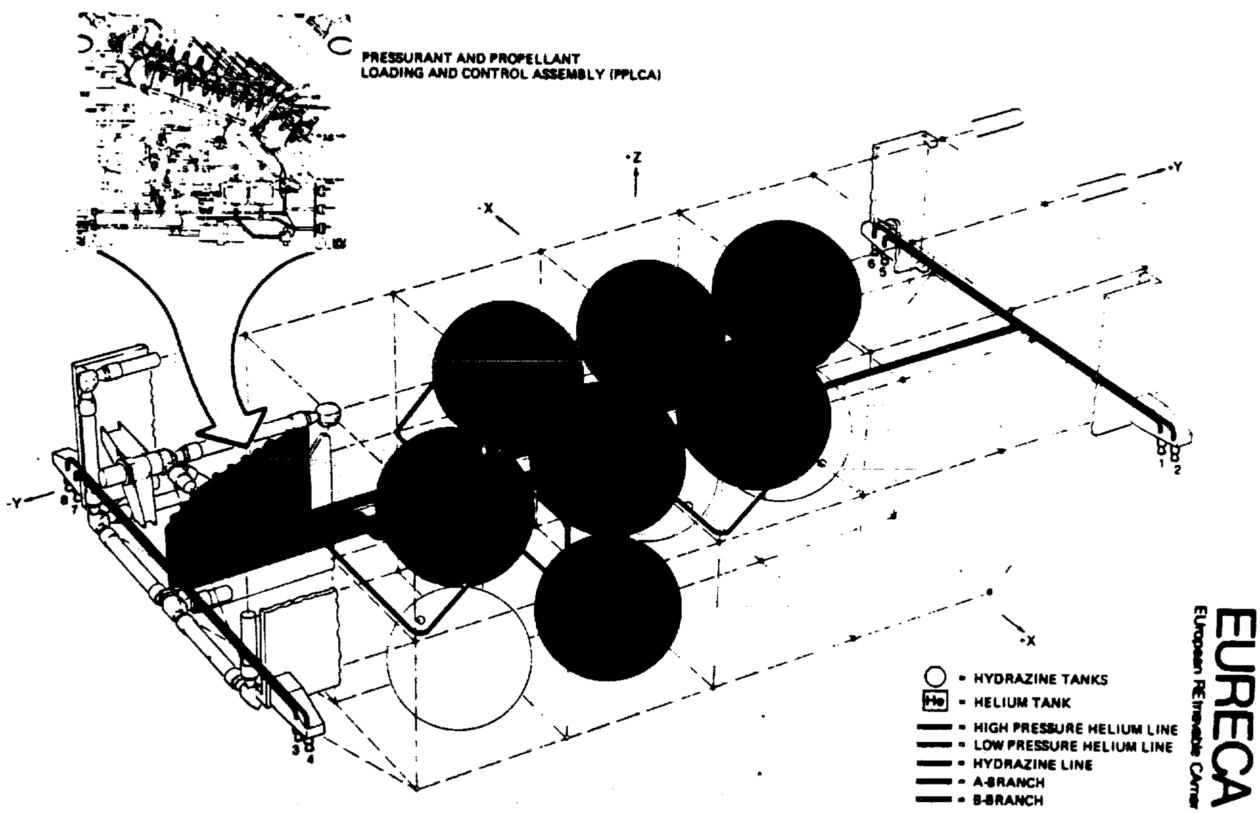
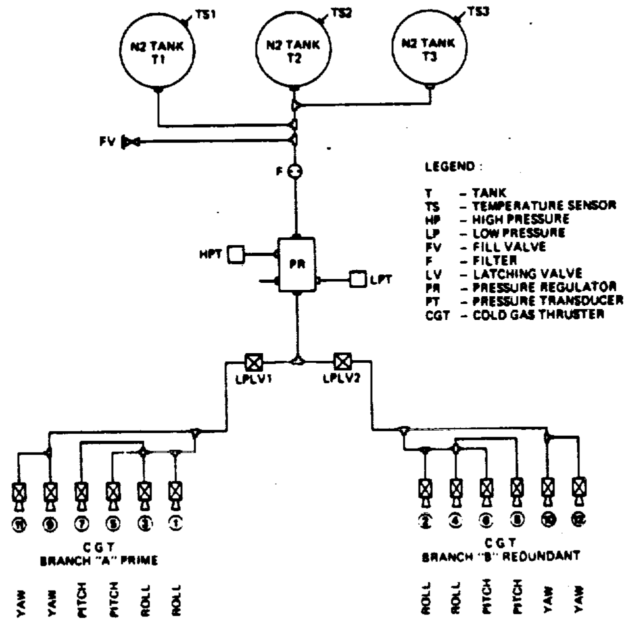
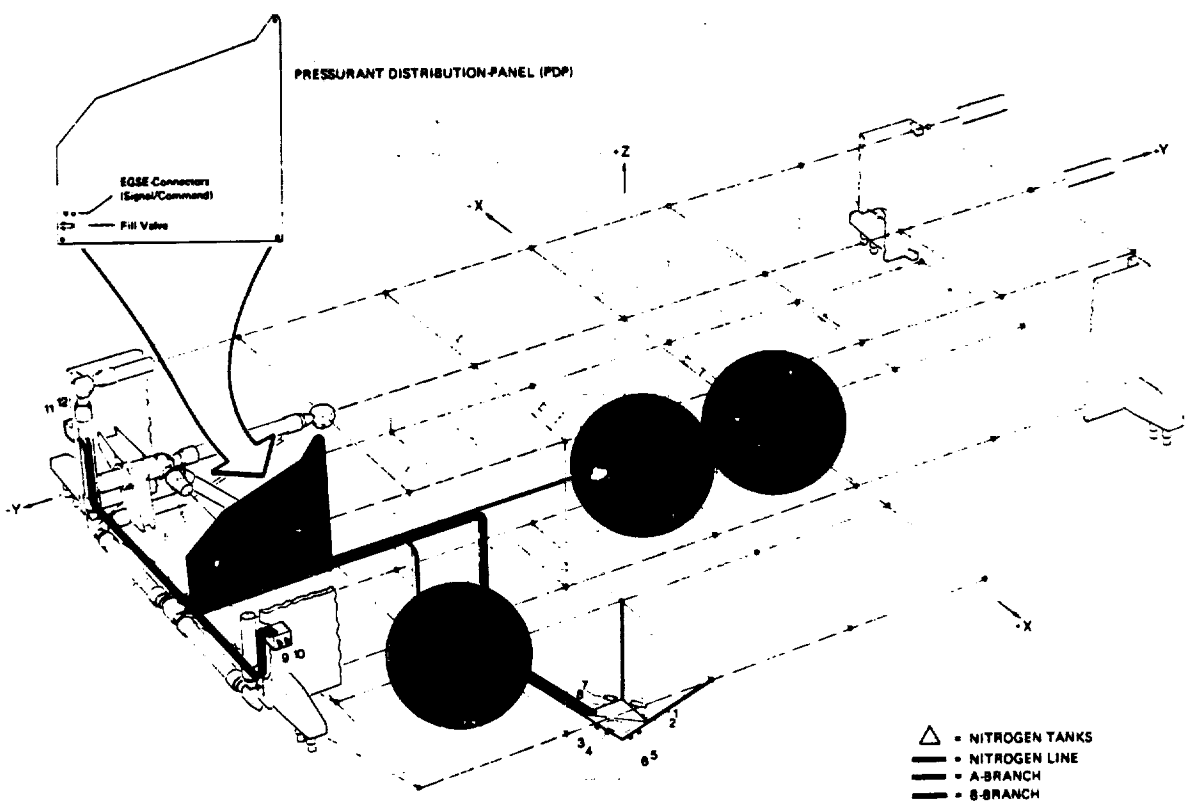






EURECA ORBIT TRANSFER ASSEMBLY (OTA)





EURECA REACTION CONTROL ASSEMBLY (RCA)

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ADAPTATION OF ON-ORBIT TRANSFER AND REACTION CONTROL ASSEMBLIES

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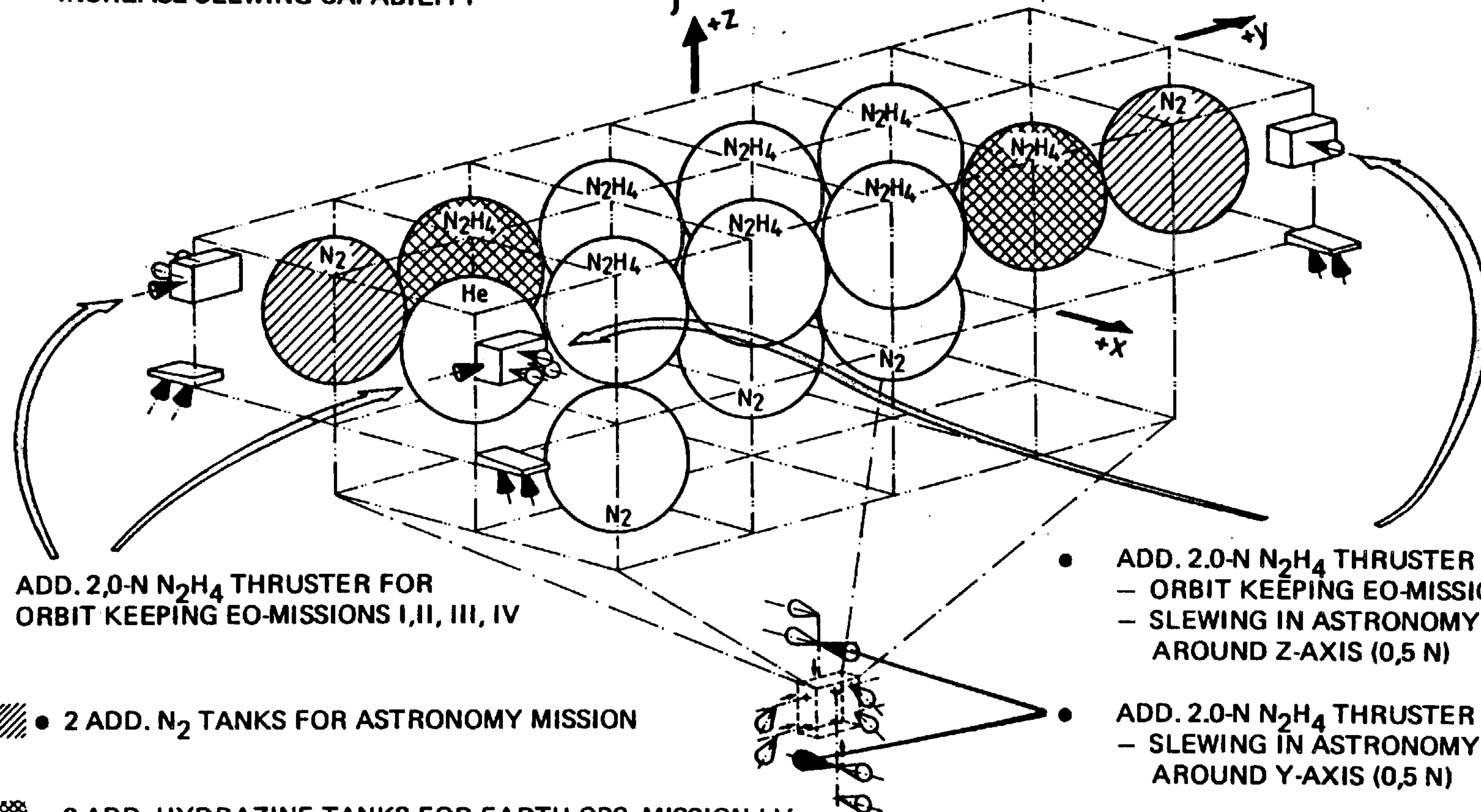
EUropean REtrievable CArrier

- OBJECTIVE OF ADAPTATION :
  - HIGHER ORBITAL ALTITUDES } EARTH OBS. MISSIONS
  - ORBIT ALTITUDE KEEPING } EARTH OBS. MISSIONS
  - COMPENSATE HIGHER DISTURBANCE TORQUES } ASTRONOMY MISSION
  - INCREASE SLEWING CAPABILITY } ASTRONOMY MISSION



- ADD. 2,0-N N_2H_4 THRUSTER FOR ORBIT KEEPING EO-MISSIONS I, II, III, IV

- ADD. 2.0-N N_2H_4 THRUSTER FOR :
  - ORBIT KEEPING EO-MISSION III, V
  - SLEWING IN ASTRONOMY MISSION AROUND Z-AXIS (0,5 N)

- ADD. 2.0-N N_2H_4 THRUSTER FOR :
  - SLEWING IN ASTRONOMY MISSION AROUND Y-AXIS (0,5 N)

(hatched) • 2 ADD. N_2 TANKS FOR ASTRONOMY MISSION

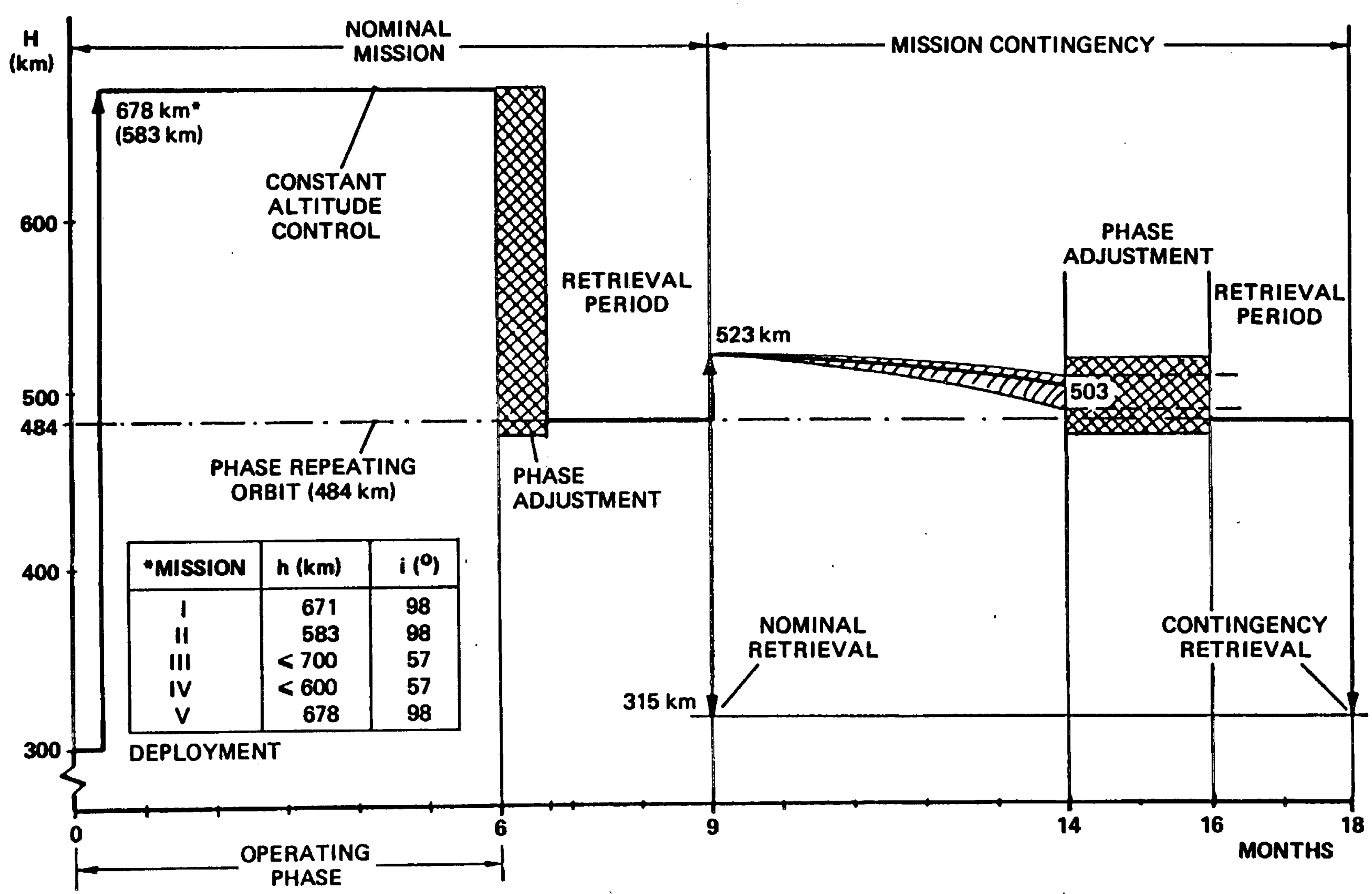
(cross-hatched) • 2 ADD. HYDRAZINE TANKS FOR EARTH OBS. MISSION I-V

◀ HYDRAZINE THRUSTER

◁ N_2 THRUSTER

EURECA
EUropean REtrievable CArrier

EARTH OBSERVATION MISSION PROFILE



*MISSION	h (km)	i (°)
I	671	98
II	583	98
III	< 700	57
IV	< 600	57
V	678	98

EURECA FUNCTIONS IN SUPPORT OF RENDEZ-VOUS AND PROXIMITY OPERATIONS (cont'd)

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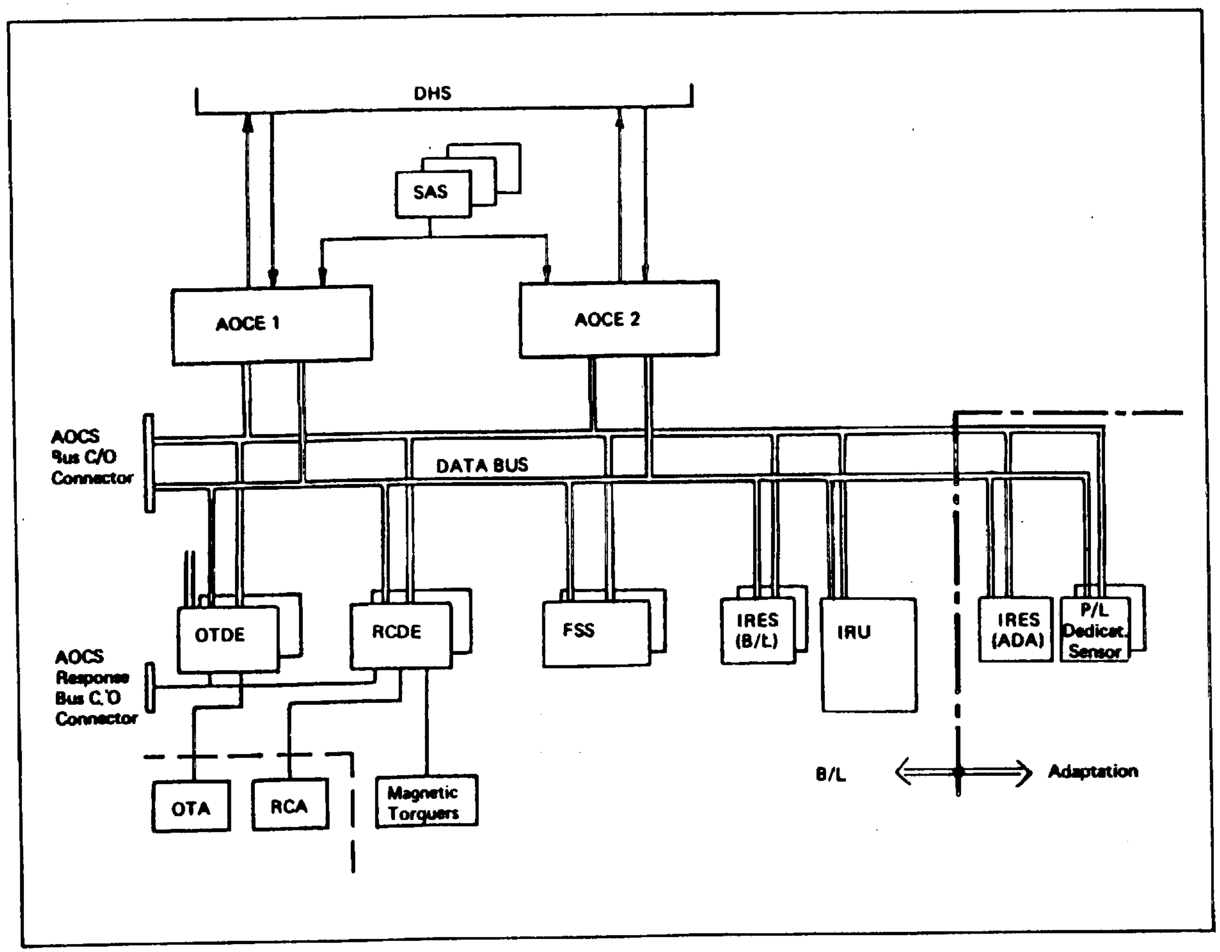
- O <u>GUIDANCE, NAVIGATION AND CONTROL (GN&C)</u>
  - o THREE-AXIS ATTITUDE DETERMINATION, ACQUISITION AND CONTROL
  - o DELTA-V CONTROL COMMANDS
  - o MOMENTUM MANAGEMENT
  - o AUTONOMOUS FAILURE DETECTION, ISOLATION AND RECONFIGURATION
  - o CONTROL AND SAFING FOR PROX OPS ASSOCIATED WITH DEPLOYMENT, RETRIEVAL AND BERTHING
  - o ESTABLISH SAFE ATTITUDE MODES (SURVIVAL) WITH ADEQUATE POWER COLLECTION AND CONTROL CAPABILITY.
  - o ON BOARD CALIBRATION OF SENSORS
  - o CONTROL OF REACTION CONTROL THRUSTERS
  - o EURECA PLATFORM POSITION DETERMINATION
    - S-BAND DOPPLER TRACKING BY GROUND STATIONS
    - INTER-ORBIT COMMUNICATION (IOC) TONE RANGING VIA ESA'S OLYMPUS SATELLITE
    - GPS RECEIVER CONSIDERED DURING PHASE B, BUT NOT IMPLEMENTED FOR EURECA-I
    - RADAR TRANSPONDER CONSIDERED DURING PHASE B, BUT NOT REQUIRED.

EURECA AOCS

EURECA
EUropean REtrievable CArrier



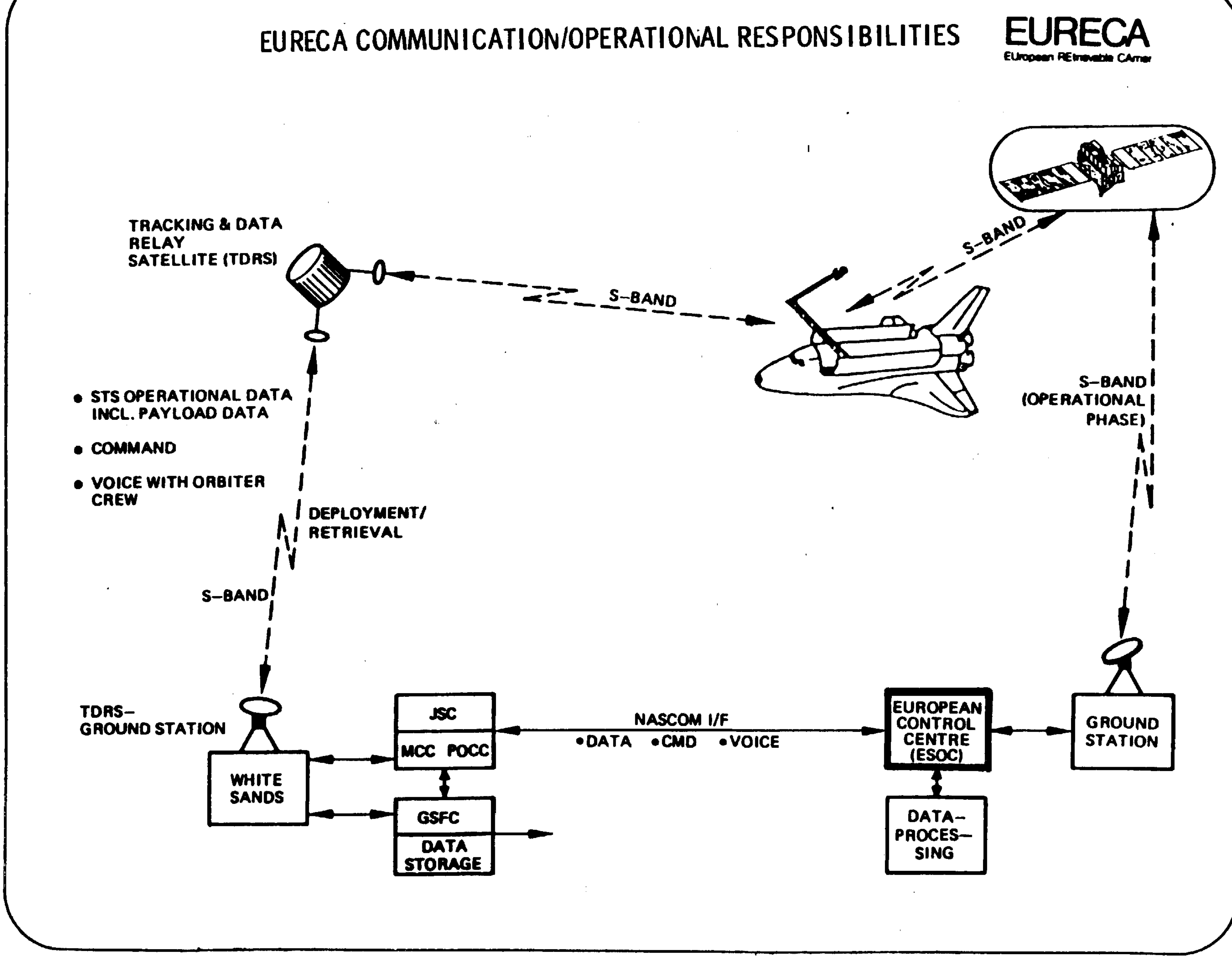
EURECA FUNCTIONS IN SUPPORT OF RENDFZ-VOUS AND PROXIMITY OPERATIONS (cont'd)

EURECA
EUropean REtrievable CArrier

- COMMUNICATION AND TRACKING
  - TM/TC TO ESA GROUND STATIONS (S-BAND)
  - TM/TC VIA ESA'S OLYMPUS SATELLITE (STEERABLE ANTENNA)
  - PI(RF) LINK BETWEEN ORBITER AND EURECA (S-BAND)
  - SUPPORTS TRACKING BY ESA GROUND STATIONS AND VIA IOC/OLYMPUS
  - DEPLOYABLE/RETRACATBLE ANTENNAE

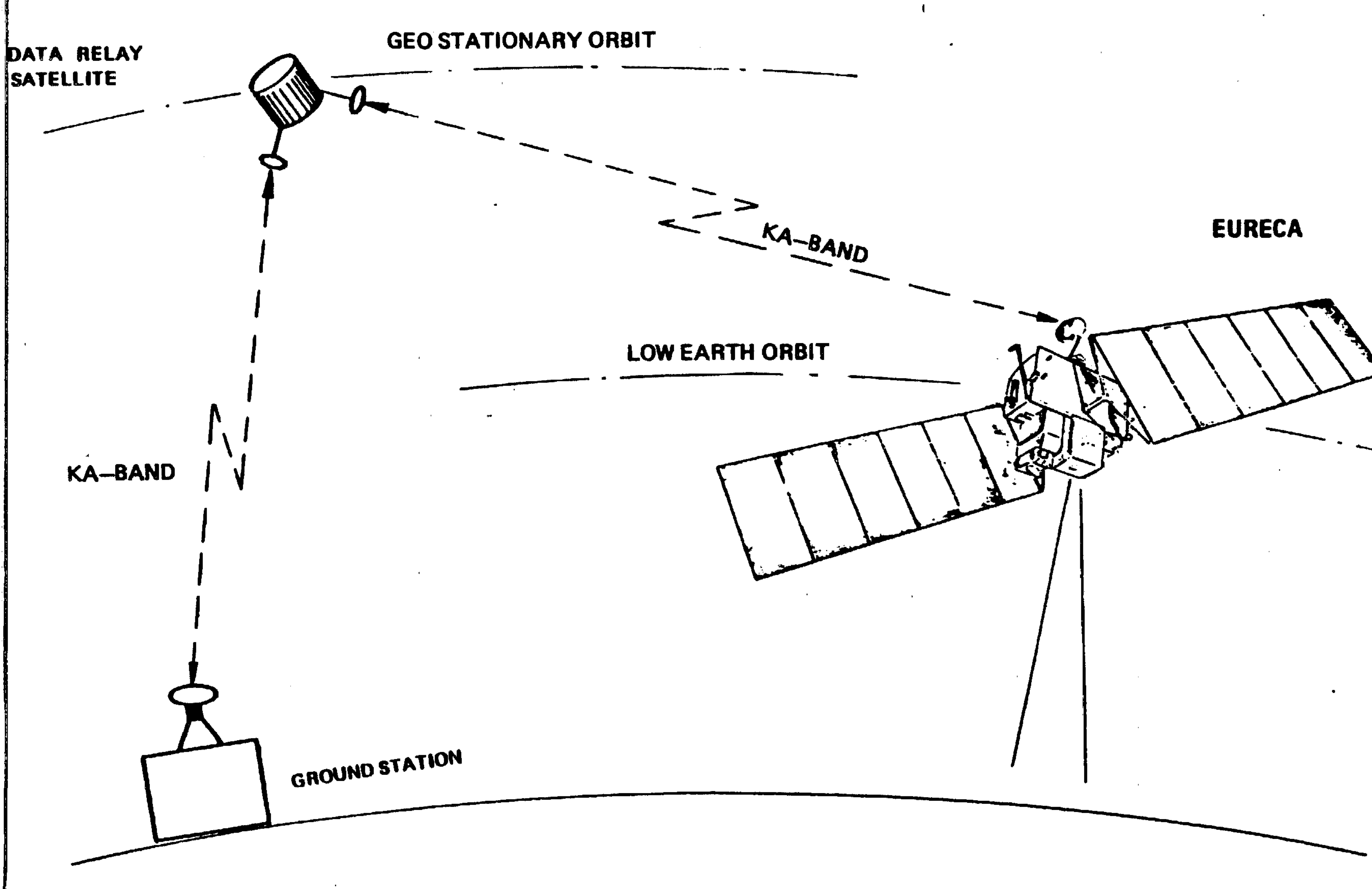
- INFORMATION AND DATA MANAGEMENT
  - EMPLOYS DISTRIBUTED ARCHITECTURE
  - COMMAND PROCESS INCLUDES RECEPTION, VALIDATION EXPANSION INTERPRETATION, STORAGE, DISTRIBUTION AND EXECUTION OF COMMANDS IN PACKET FORM
  - DATA COLLECTION AND PROCESSING OF SCIENCE AND ENGINEERING DATA PACKETS
  - MAGNETIC BUBBLE MEMORY FOR DATA STORAGE DURING NON COVERAGE PERIODS
  - MONITORS THE PLATFORM HEALTH AND STATUS IN SUPPORT OF AUTONOMOUS OPERATION.

EURECA COMMUNICATION/OPERATIONAL RESPONSIBILITIES



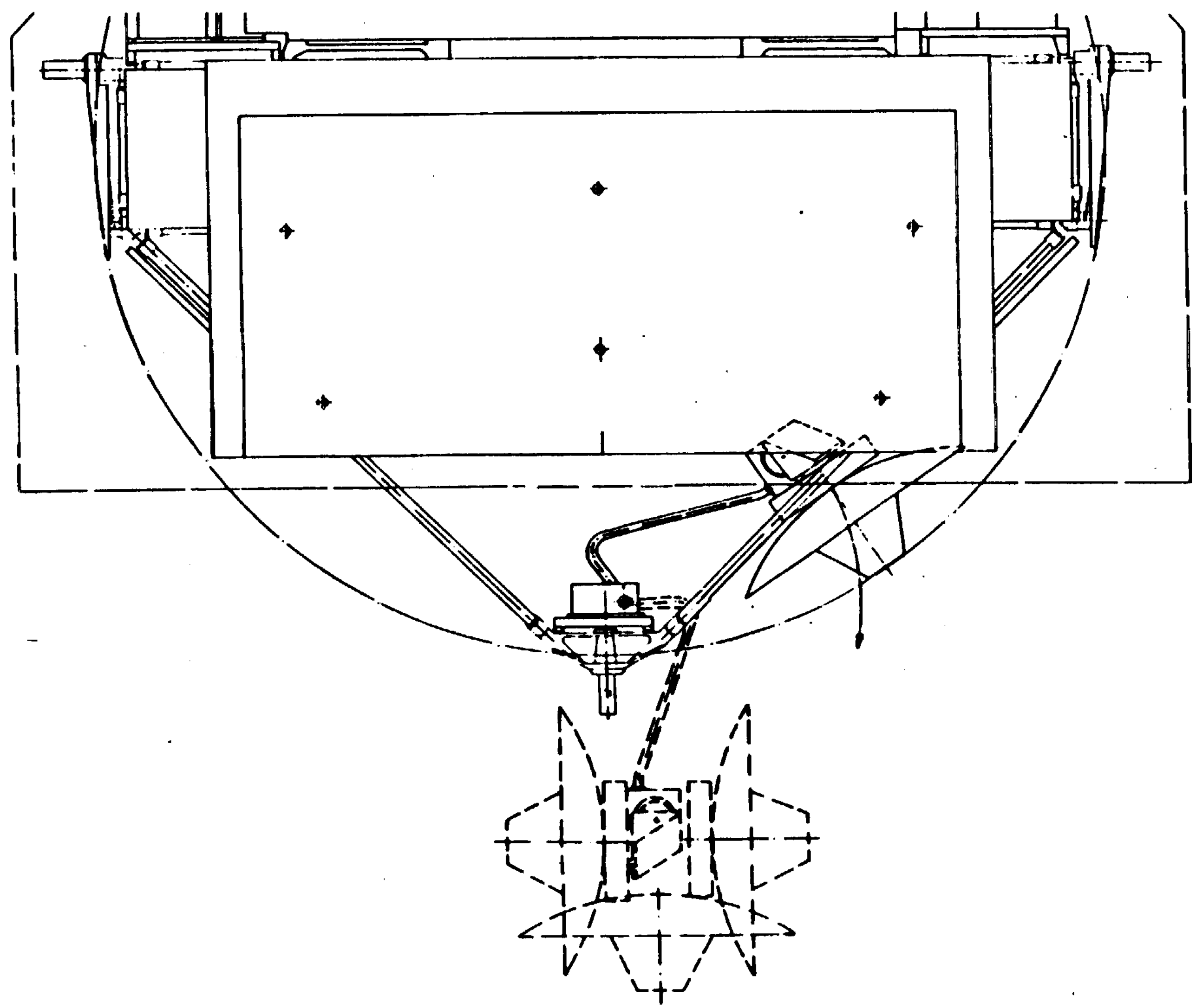
INTER-ORBIT COMMUNICATION LINK

EURECA
EUropean REtrievable CArrier



ACCOMMODATION OF ANTENNA FOR IOC-LINK

EURECA
EUropean REtrievable CArrier



EURECA FUNCTIONS IN SUPPORT OF RENDEZ-VOUS AND PROXIMITY OPERATIONS (cont'd)

EURECA
EUropean REtrievable CArrier

- ELECTRICAL POWER
  - DEPLOYABLE/RETRACTABLE SOLAR ARRAYS
  - NICD-BATTERIES TOGETHER WITH THE SOLAR ARRAYS PROVIDE CONTINUOUS POWER PER ORBIT ALLOWING FLEXIBILITY FOR NIGHT/DAYLIGHT PROXIMITY OPERATIONS TIMELINE

- EURECA/STS INTERFACES
  - STANDARD DIRECT 3-POINT STRUCTURAL ATTACHMENT
  - DEPLOYMENT/GRAPPLE WITH RMS
  - REMOTELY REMATABLE POWER AND DATA UMBILICAL
  - FLIGHT ELECTRICAL GRAPPLE FIXTURE (FEGF)/SPEE INTERFACE FOR INITIAL ACTIVATION/FINAL DEACTIVATION AND AS BACKUP FOR UMBILICAL DURING RETRIEVAL MISSION.

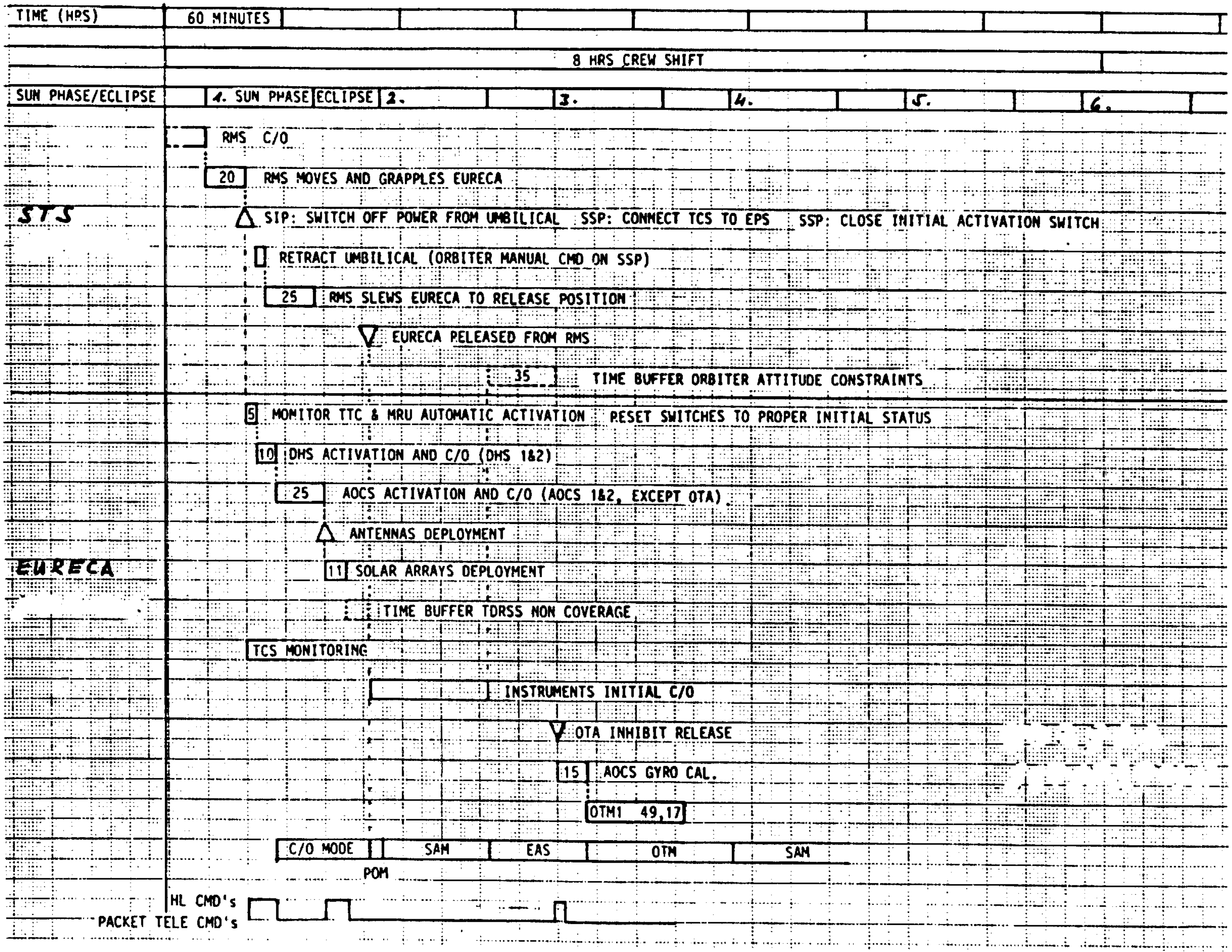
EURECA DEPLOYMENT AND SEPARATION

EURECA
EUropean REtrievable CArrier

- DEPLOYMENT
  - REMOTE MANIPULATOR SYSTEM
- INITIAL SEPARATION
  - IMPULSE PROVIDED BY ORBITER RCS
  - RELATIVE SPEED 0.15 M/SEC (0.5 FT/SEC) MINIMUM
  - DIRECT VISUAL OBSERVATION UNTIL 61 M (200 FT) SEPARATION
  - EURECA HYDRAZINE THRUSTERS INHIBITED UNTIL SAFE SEPARATION DISTANCE OF 275 FT IS ACHIEVED (WITHIN 10 MIN FOLLOWING RELEASE)
- COMMUNICATION
  - THE ORBITER PROVIDES PI(RF) LINK AND RENDEZ-VOUS CAPABILITY BY REMAINING WITHIN 10 KM RELATIVE DISTANCE DURING EURECA CHECKOUT AND COMMISSIONING WITHIN THE SAME CREW DAY.
  - ALL MONITORING AND CONTROL FUNCTIONS ARE PERFORMED FROM ESOC VIA MCC-HOUSTON AND ORBITER PI(RF) LINK OR BY DIRECT COMMUNICATION TO/FROM ESA GROUND STATIONS.

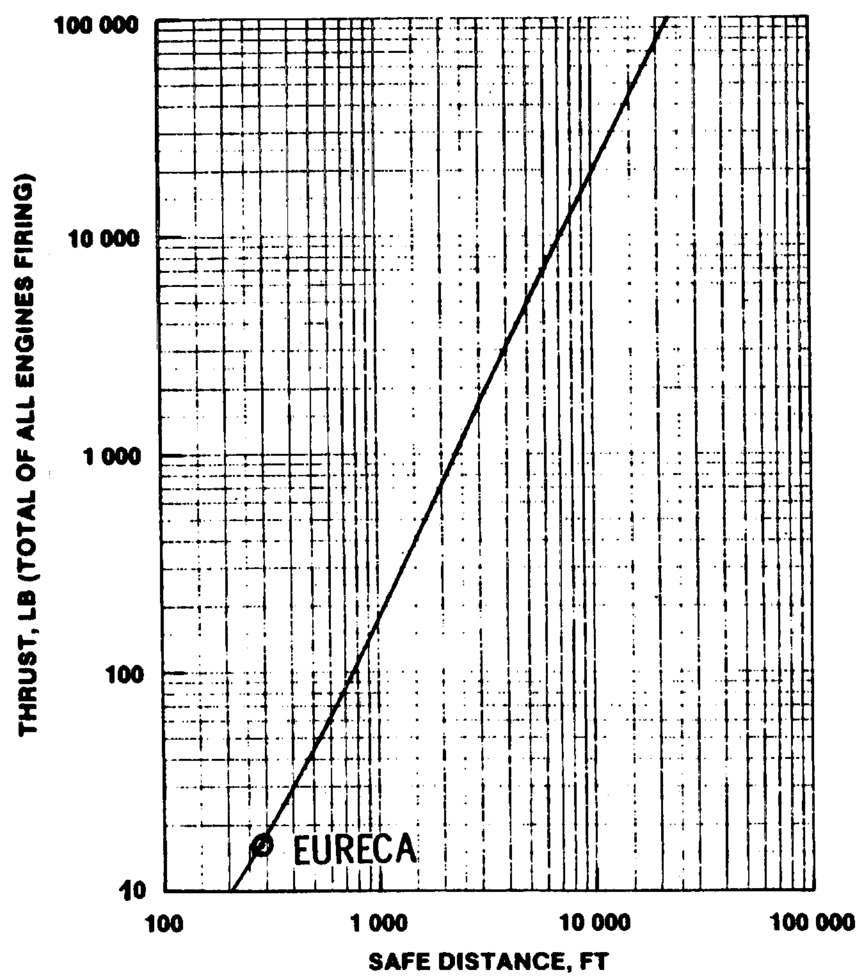
EURECA ACTIVATION DURING DEPLOYMENT

EURECA
European REtrievable CArrier



SAFE DISTANCE FOR FIRING LIQUID PROPULSION ENGINES

EURECA
EUropean REtrievable CArrier



EURECA RETRIEVAL

EURECA
EUropean REtrievable CArrier

- O RETRIEVAL POLICY AND REQUIREMENTS FOR STANDARD SHARED DEPLOYMENT/RETRIEVAL MISSIONS ESTABLISHED IN 1983/1984.
- O EUREKA PERFORMS PHASE AND RAAN CORRECTION
- O EURECA DESCENDS TO RETRIEVAL ORBIT FOLLOWING SHUTTLE LAUNCH
- O EURECA PERFORMS RENDEZ-VOUS WITH PHANTOM POINT IN ORBIT (CONTROL BOX)
- O ORBITER PERFORMS RENDEZ-VOUS AND PROXIMITY TRAJECTORIES WITH EURECA AS A PASSIVE TARGET
- O DEACTIVATION OF EURECA ACCORDING TO NHB 1700.A

EURECA RETRIEVAL TECHNICAL SPECIFICATIONS
FOR SHARED DEPLOYMENT/RETRIEVAL MISSION.

EURECA
EUropean REtrievable CArrier

1. NOMINAL RENDEZ-VOUS ORBIT PARAMETERS:

A. INCLINATION : 28.45 DEGREES
B. ALTITUDE : 170 N.M., CIRCULAR

2. INITIAL TARGET STATE

PRIOR TO THE PLANNING FOR THE SCHEDULED DEPLOYMENT LAUNCH, ESA WILL SPECIFY TO NASA A PREDICTED DELTA-RAAN HISTORY; THIS IS, THE PREDICTED LOCATION OF THE ASCENDING NODE OF EURECA'S ORBIT, RELATIVE TO THE ASCENDING NODE AT THE TIME OF DEPLOYMENT, AS A FUNCTION OF TIME COVERING THE PERIOD TO THE EURECA DESIRED RETRIEVAL DATE PLUS 90 DAYS OR A 9-MONTH PERIOD, WHICHEVER IS GREATER. WITHIN ONE HOUR AFTER DEPLOYMENT ESA WILL BE PROVIDED WITH (1) THE ACTUAL RAAN, DATE AND TIME OF THE DEPLOYMENT. AND (2) AN INITIAL TARGET RAAN, DATE AND TIME OF THE RETRIEVAL. THE INITIAL TARGET RAAN WILL BE SPECIFIED SUCH THAT IT COULD BE ACHIEVED VIA A VARIATION TO THE PREDICTED DELTA-RAAN HISTORY PROFILE OF NO MORE THAN 0.1 DEGREES PER DAY OVER THE RETRIEVAL INTERVAL.

3. UPDATED TARGET STATE

AT LEAST 30 DAYS PRIOR TO THE UPDATED TARGET DATE, ESA WILL BE PROVIDED WITH (1) AN UPDATE TO THE INITIAL TARGET RAAN, DATE AND TIME, AND (2) THE REQUIRED EURECA RENDEZ-VOUS PHASE ANGLE. THE UPDATED TARGET RAAN WILL INCORPORATE TWO ADJUSTMENTS TO THE INITIAL VALUE: (1) ADJUSTMENT BASED ON THE NODAL REGRESSION RATE OF A PHASE-REPEATING ORBIT WITH A CIRCULAR ALTITUDE OF APPROXIMATELY 257 N.M, AND (2) A FIXED BIAS ADJUSTMENT WITHIN $\pm$ 1 DEGREE. EURECA WILL HAVE A 360-DEGREE PHASING CAPABILITY.

4. FINAL TARGET STATE

AFTER LAUNCH, ESA WILL BE PROVIDED WITH THE FOLLOWING:

A. A GO FOR DESCENT

B. THE FINAL TARGET RAAN AND PHASE - THE FINAL TARGET RAAN WILL INCORPORATE TWO ADJUSTEMENTS TO THE UPDATE VALUE; THE FIRST WILL BE BASED ON THE NODAL REGRESSION RATE OF A PHASE REPEATING ORBIT WITH A CIRCULAR ALTITUDE OF APPROXIMATELY 257 N. MI., AND THE SECOND WILL BE A FIXED BIAS ADJUSTMENT WITHIN PLUS OR MINUS 0.1 DEGREE. THE FINAL TARGET PHASE WILL INCLUDE AN ADJUSTMENT WITHIN PLUS OR MINUS TBD DEG TO THE PHASE REQUIREMENT STIPULATED IN ITEM 3. ABOVE.

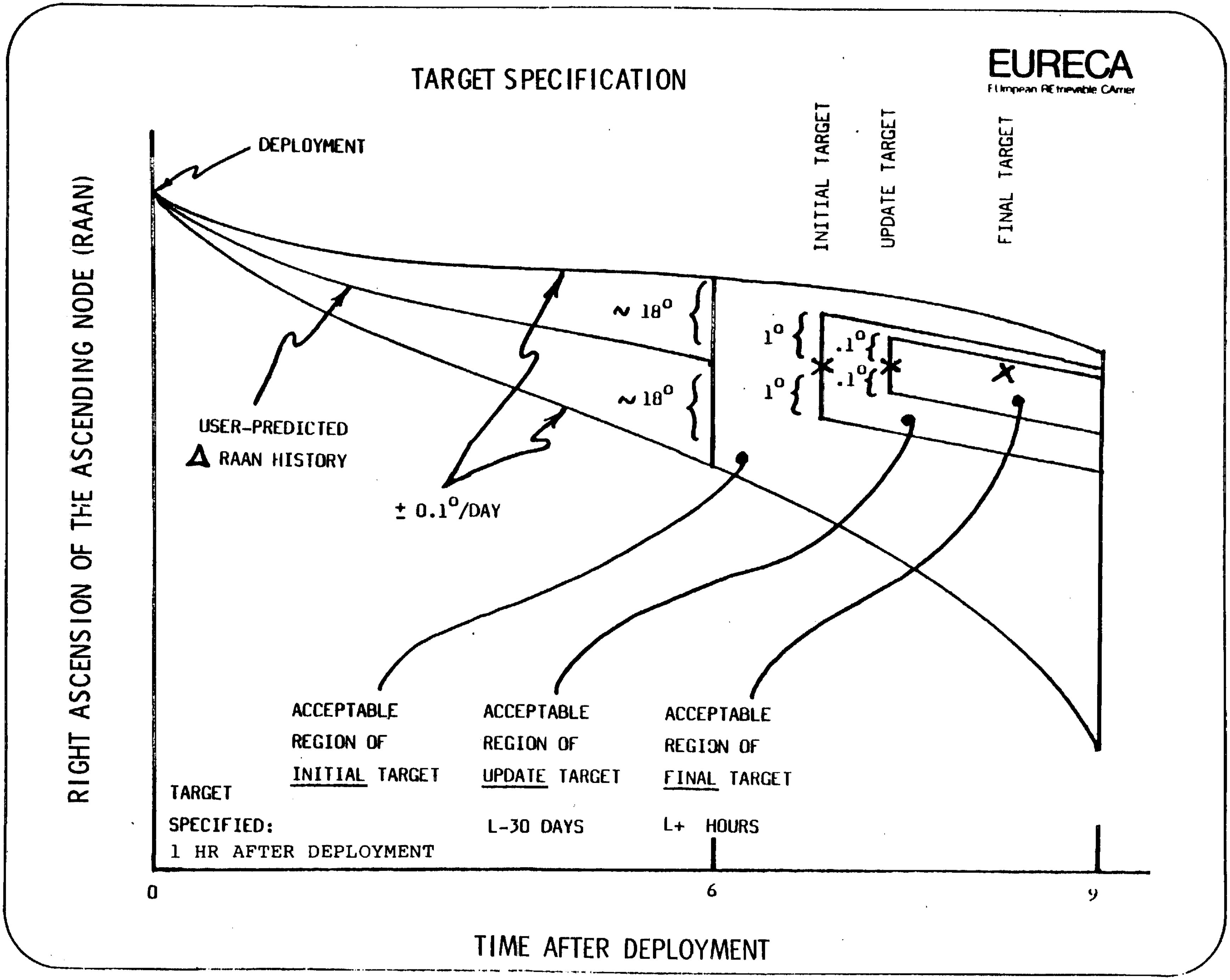
EURECA RETRIEVAL TECHNICAL SPECIFICATIONS (cont'd)

EURECA
EUropean REtrievable CArrier

C. THE CONTROL BOX START TIME - THE CONTROL BOX START TIME IS THE TIME WHEN EURECA SHALL BE IN ITS DESIGNATED RENDEZ-VOUS CONTROL BOX AND SHALL CEASE ALL TRANSLATIONAL MANOEUVERING. THE CONTROL BOX START TIME WILL BE NO EARLIER THAN 72 HR AFTER THE GO FOR DESCENT FOR THE INITIAL EURECA RETRIEVAL MISSION IS ISSUED, AND NO EARLIER THAN 48 HR AFTER THE GO FOR DESCENT IS ISSUED FOR SUBSEQUENT MISSIONS. ALSO, AT THE CONTROL BOX START TIME, ESA WILL PROVIDE NASA WITH A PAYLOAD STATE VECTOR WHICH SHALL BE WITHIN THE FOLLOWING MAXIMUM ERROR AND UNCERTAINTY LIMITS:

1. MAXIMUM STATE ERROR LIMITS - TBD

2. MAXIMUM STATE UNCERTAINTY LIMITS - TBD


TARGET SPECIFICATION
EURECA
EUropean REtrievable CArrier
DEPLOYMENT
USER-PREDICTED
Δ RAAN HISTORY
± 0.1°/DAY
~ 18°
~ 18°
1°
1°
.1°
.1°
INITIAL TARGET
UPDATE TARGET
FINAL TARGET
ACCEPTABLE REGION OF INITIAL TARGET
ACCEPTABLE REGION OF UPDATE TARGET
ACCEPTABLE REGION OF FINAL TARGET
TARGET SPECIFIED:
1 HR AFTER DEPLOYMENT
L-30 DAYS
L+ HOURS
0
6
9
TIME AFTER DEPLOYMENT
RIGHT ASCENSION OF THE ASCENDING NODE (RAAN)

EUREČA
European REtrievable CArrier

PRELIMINARY CONTROL BOX DEFINITION.

0 STATE ERROR LIMITS

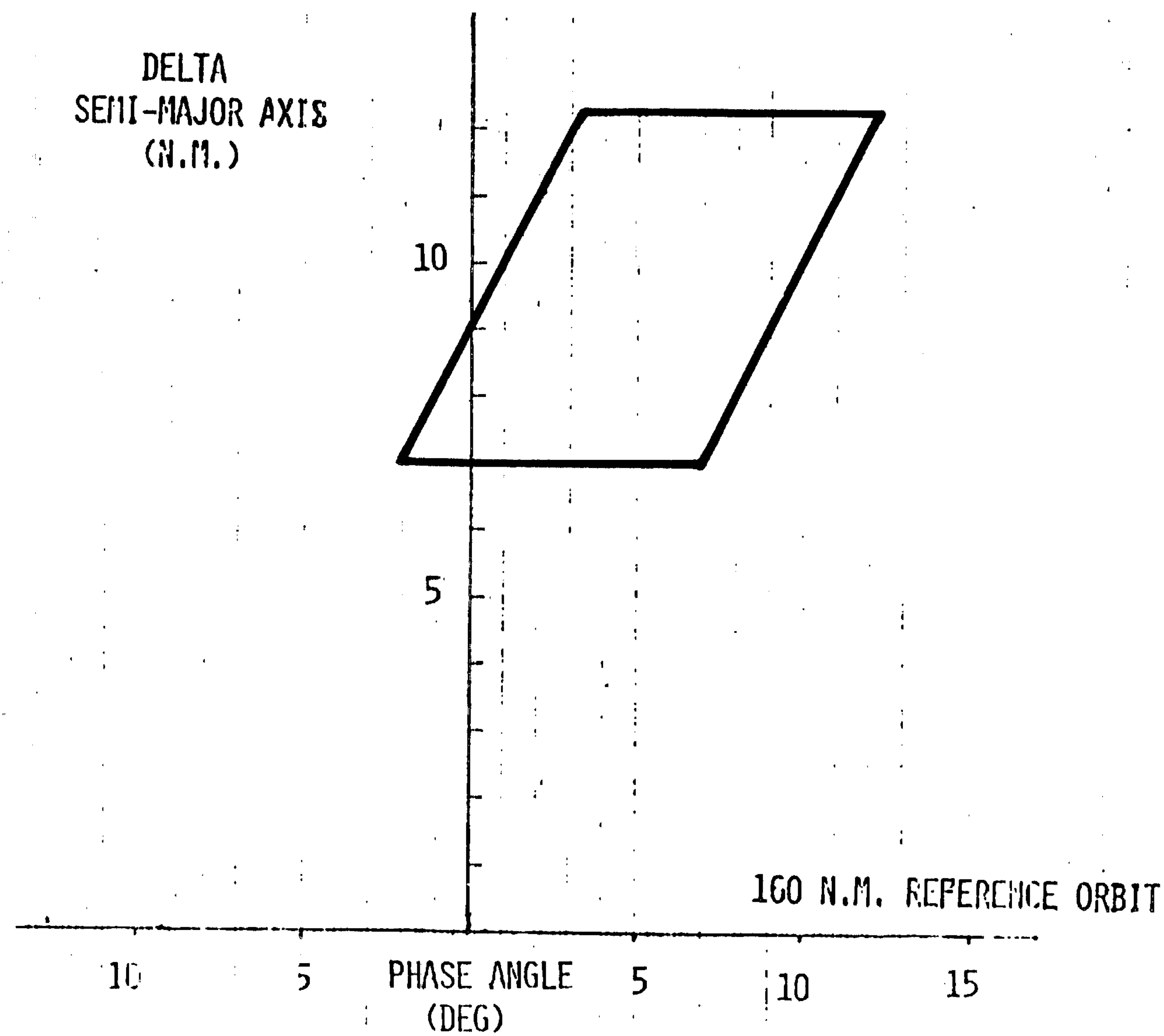
- o ORBIT PLANE ERROR
  - MAXIMUM OF 0.02°
- o ORBIT ECCENTRICITY
  - MAXIMUM OF 2 NMI
- o ORBIT ENERGY AND PHASE ANGLE
  - ACCEPTABLE REGION SHOWN ON NEXT CHART

0 STATE UNCERTAINTY LIMITS

COORDINATE	ONE SIGMA VARIATION
U (RADIAL)	40 FT
V (ALONG TRACK)	900 FT
W (CROSS TRACK)	300 FT

EURECA

EURECA IN - PLANE CONTROL BOX
PRELIMINARY



5. RENDEZ-VOUS OPERATIONS

AT THE TIME PLANNED FOR THE RENDEZ-VOUS. EURECA SHALL BE IN A SAFE. RETRIEVABLE CONDITION, AND SHALL BE CAPABLE OF SUSTAINING THIS RETRIEVAL-READY MODE FOR AT LEAST 2 HR., INCLUDING HAVING AN ACCEPTABLE VALUE FOR ORBITER/PAYLOAD DIFFERENTIAL DRAG. PRIOR TO TERMINAL PHASE INITIATION THE ORBITER WILL ESTABLISH A DATA RELAY SERVICE VIA THE PI(PF) LINK FOR UP TO TBD MIN. AFTER REACHING THE STATION KEEPING DISTANCE OF APPROXIMATELY 1000 FT, THE ORBITER WILL PROVIDE RETRIEVAL CAPABILITY FOR A PERIOD OF TBD HR. RETRIEVAL SERVICES COMMENCE WHEN THE ORBITER HAS REACHED A DISTANCE OF APPROXIMATELY 1000 FT.

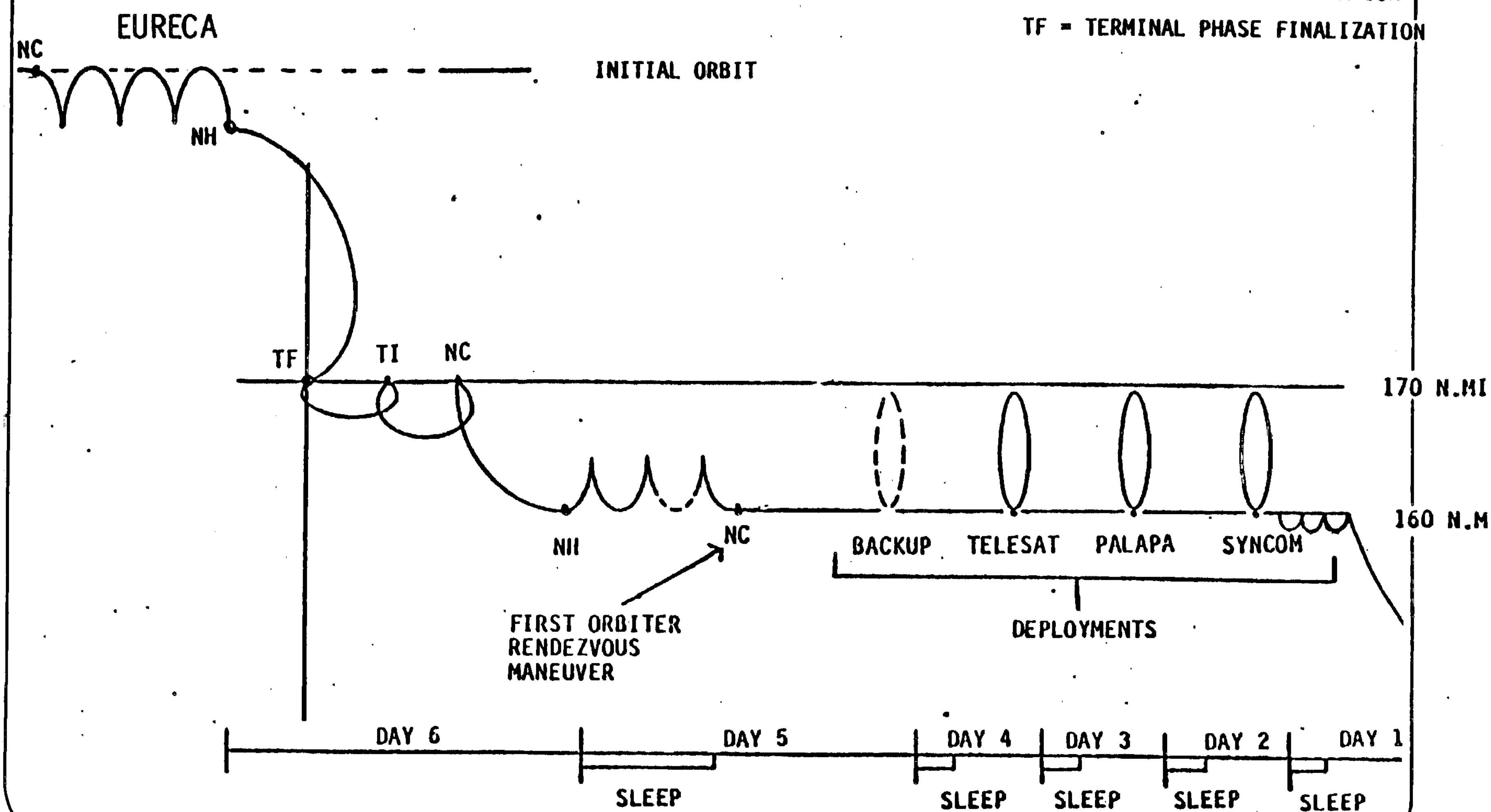
EURECA WILL BE TRACKED BY ORBITER ONBOARD NAVIGATION SENSORS. EURECA WILL BE COMPATIBLE WITH THE RENDEZ-VOUS RADAR PASSIVE MODE, THE STAR TRACKER (S TRK), AND THE CREW OPTICAL ALIGNMENT SIGHT (COAS). THE EURECA WILL PROVIDE REFLECTORS SUITABLE FOR USE WITH THE ORBITER DOCKING LIGHTS. ORBITER RENDEZ-VOUS AND RETRIEVAL MANOEUVERS WILL BE DESIGNED TO MINIMIZE PLUME IMPINGEMENT ON THE EURECA.

THE EURECA RETRIEVAL ATTITUDE WILL BE A SI ATTITUDE. THE ATTITUDE OF THE EURECA COORDINATE SYSTEM RELATIVE TO THE SUN IS +Z SOLAR.

ORBITER AND EURECA TRAJECTORY PROFILES

EURECA
EUropean REtrievable CArrier

NC = PHASING MANEUVER
NH = HEIGHT ADJUST
TI = TERMINAL PHASE INITIATION
TF = TERMINAL PHASE FINALIZATION



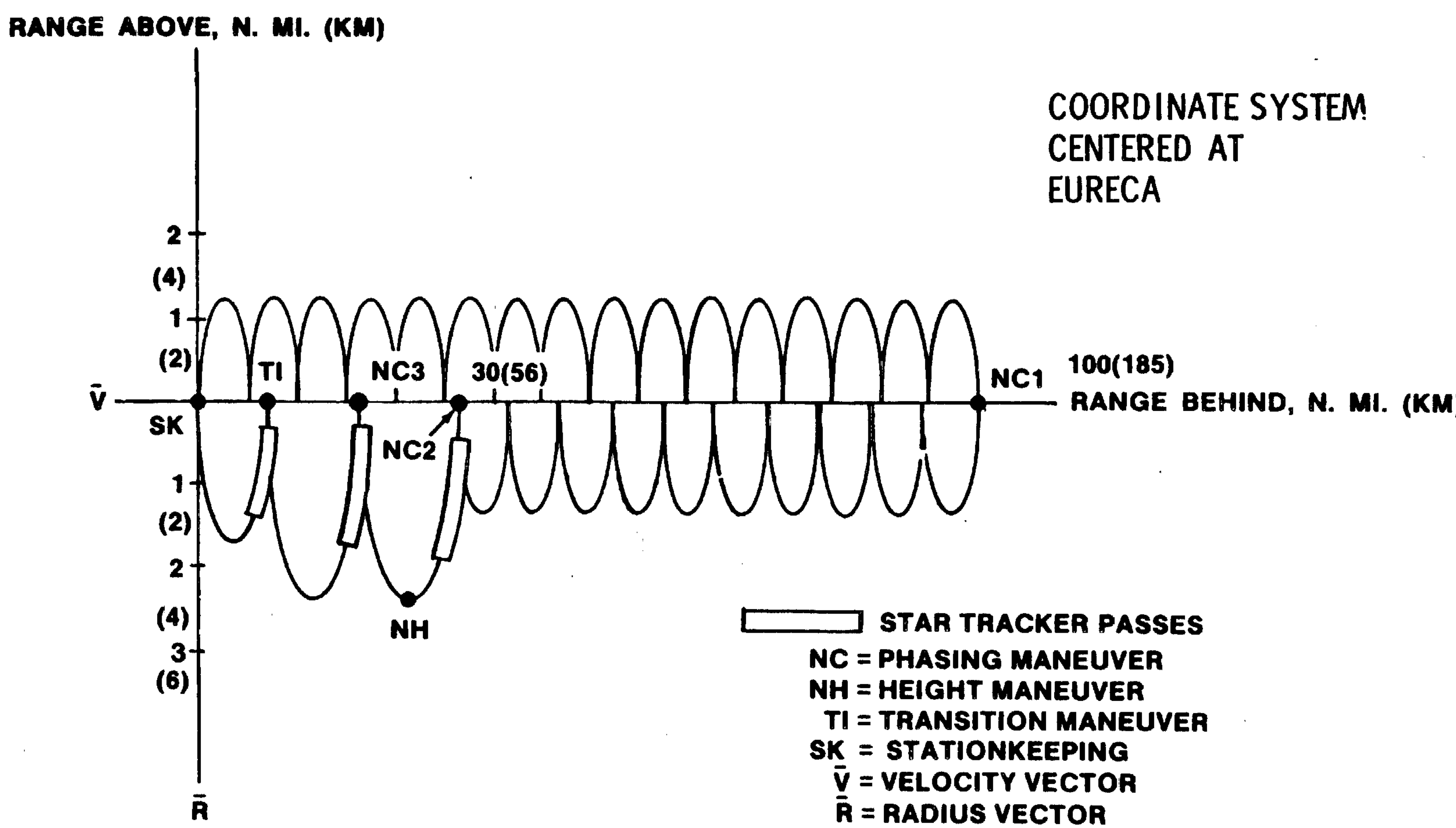
EURECA
EUropean REtrievable CArrier

STANDARD RENDEZ-VOUS PROFILE
FAR FIELD.

- STANDARD RENDEZ-VOUS PROFILE BEGINS WITH A PHASING MANOEUVER (NC I) TO SET THE PROPER CATCH UP RATE.
- TRACKING ARC PRIOR TO NCI UPDATES GROUND KNOWLEDGE OF THE EURECA STATE VECTOR (CONTROL BOX): THIS STATE IS SUBSEQUENTLY UPLINKED TO THE ORBITER
- PHASE ANGLE DIFFERENTIAL OF UP TO 10 DEGREES CAN BE ACCOMMODATED DURING THE SLEEP PERIOD FOLLOWING NC I.

RENDEZVOUS PROFILE
FAR FIELD

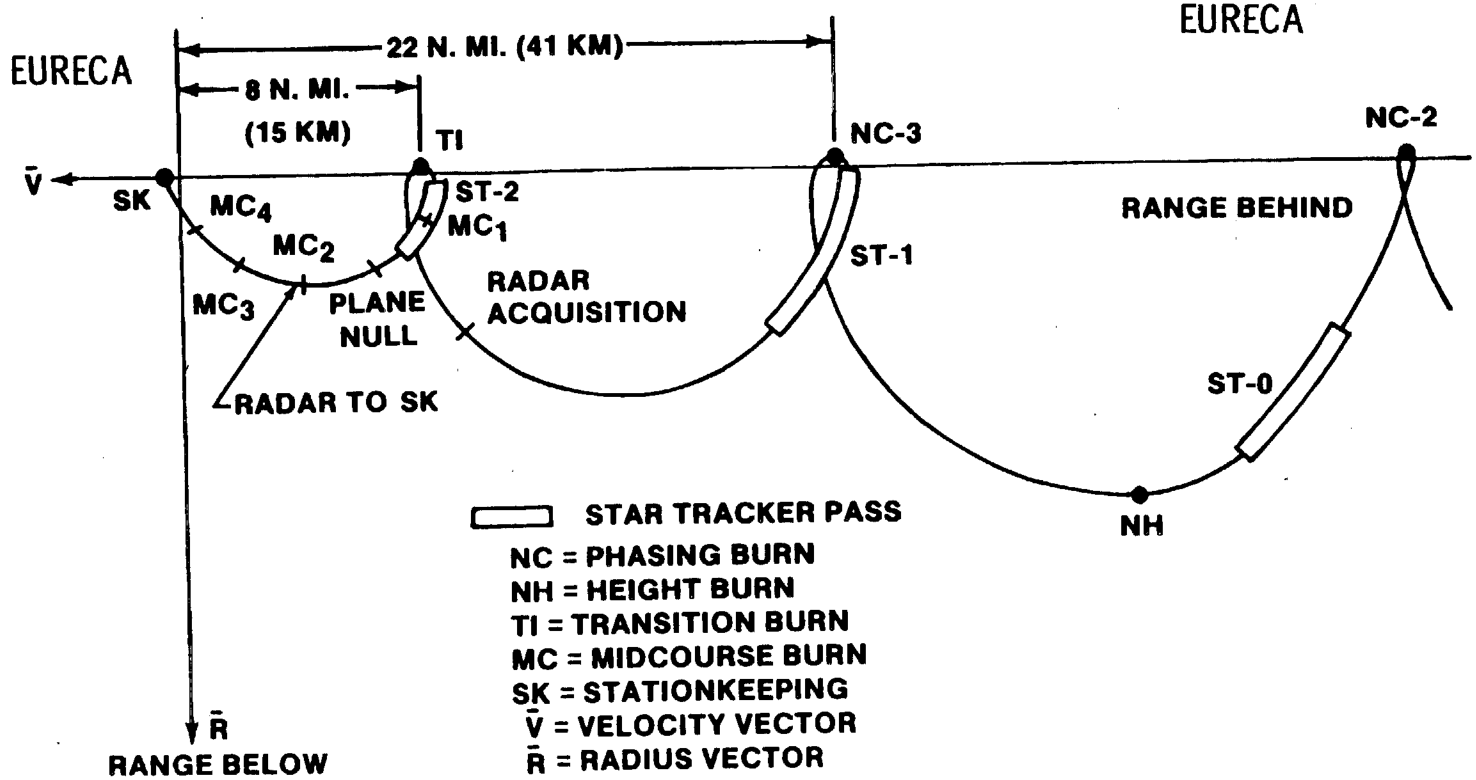
EURECA
EUropean REtrievable CArrier



RENDEZVOUS PROFILE
DAY OF RENDEZVOUS

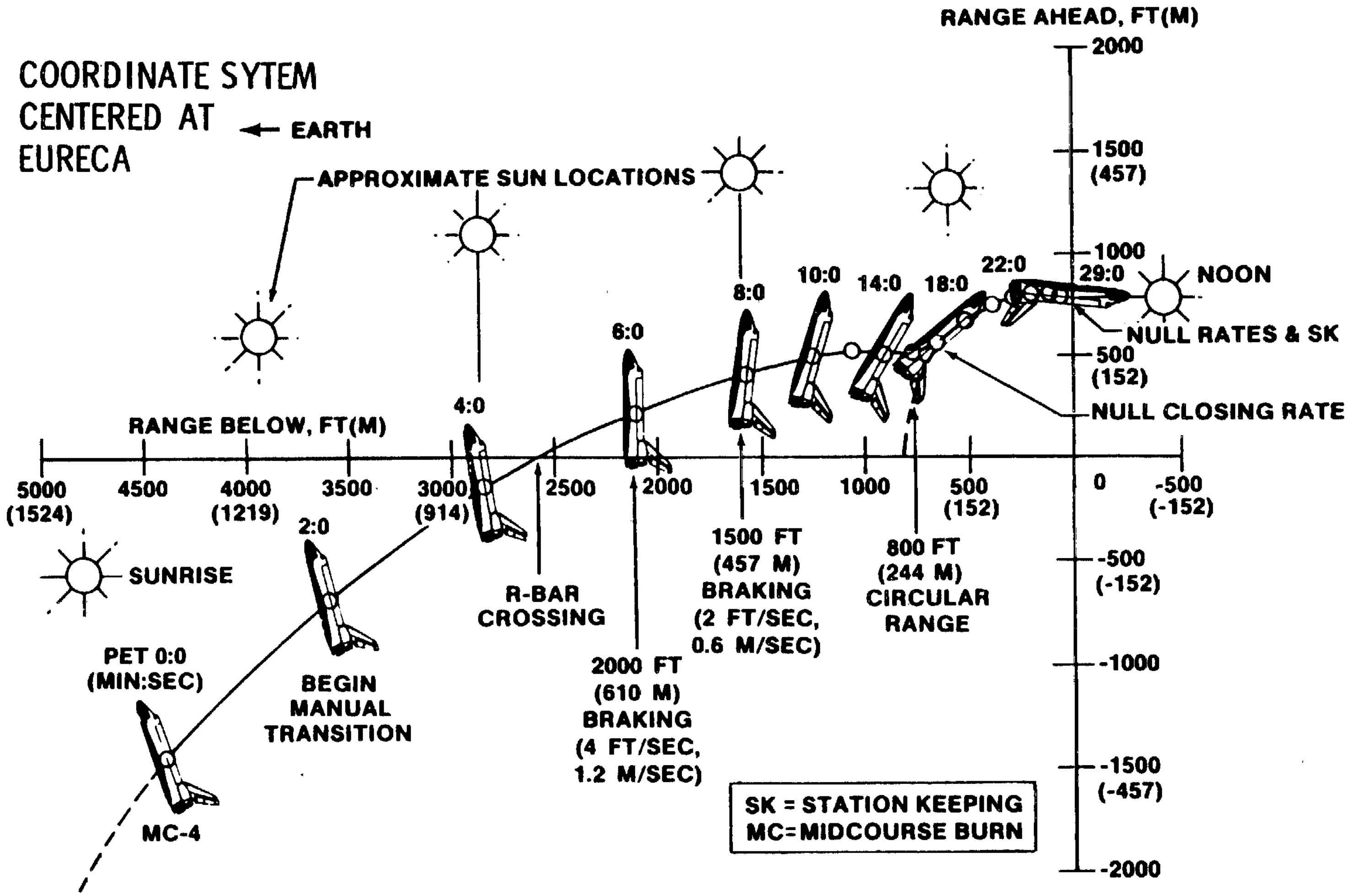
EURECA
European REtrievable CArrier

COORDINATE SYSTEM
CENTERED AT
EURECA

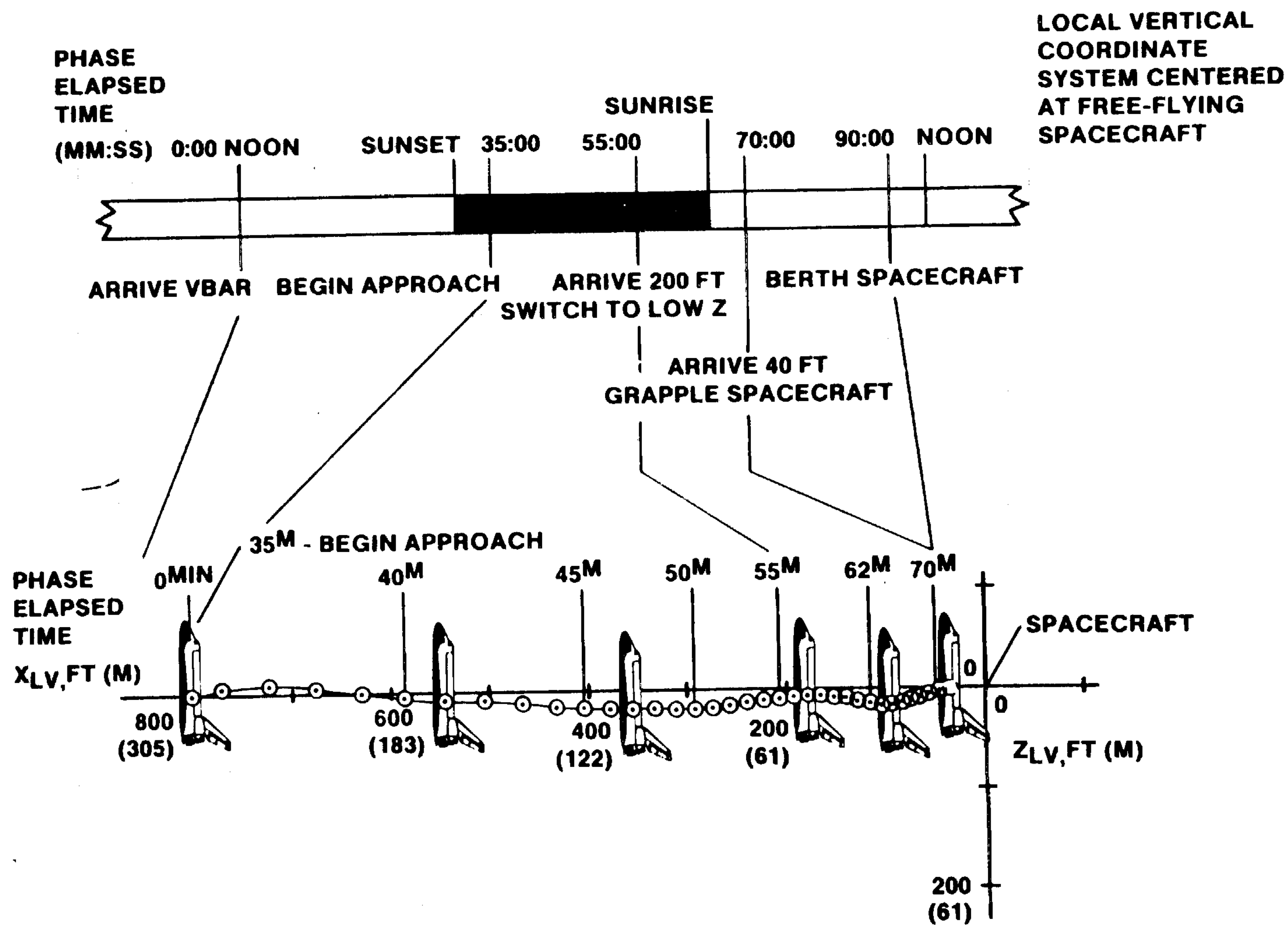


NEAR-FIELD RENDEZVOUS PROFILE

EURECA
EUropean REtrievable CArrier



APPROACH TO GRAPPLE
LVLH



6. DEACTIVATION SEQUENCE

THE EURECA DEACTIVATION IS IN ACCORDANCE WITH THE SAFETY REQUIREMENTS DOCUMENTED IN NHB 1700.7A. THE EURECA WILL USE THE NO MONITORING OPTION AS SPECIFIED IN NHB 1700.7A.

THE EURECA LIQUID PROPULSION SYSTEM WILL BE DEACTIVATED AND SAFED BY SETTING THREE INHIBITS, VERIFYING SAFE STATUS, AND DEENERGIZING THE INHIBIT CONTROL CIRCUITRY BEFORE THE ORBITER APPROACHES THE SAFE DISTANCE.

THE SOLAR ARRAY PANELS AND S-BAND ANTENNAS WILL BE RETRACTED OUTSIDE THE RESPECTIVE SAFE DISTANCES.

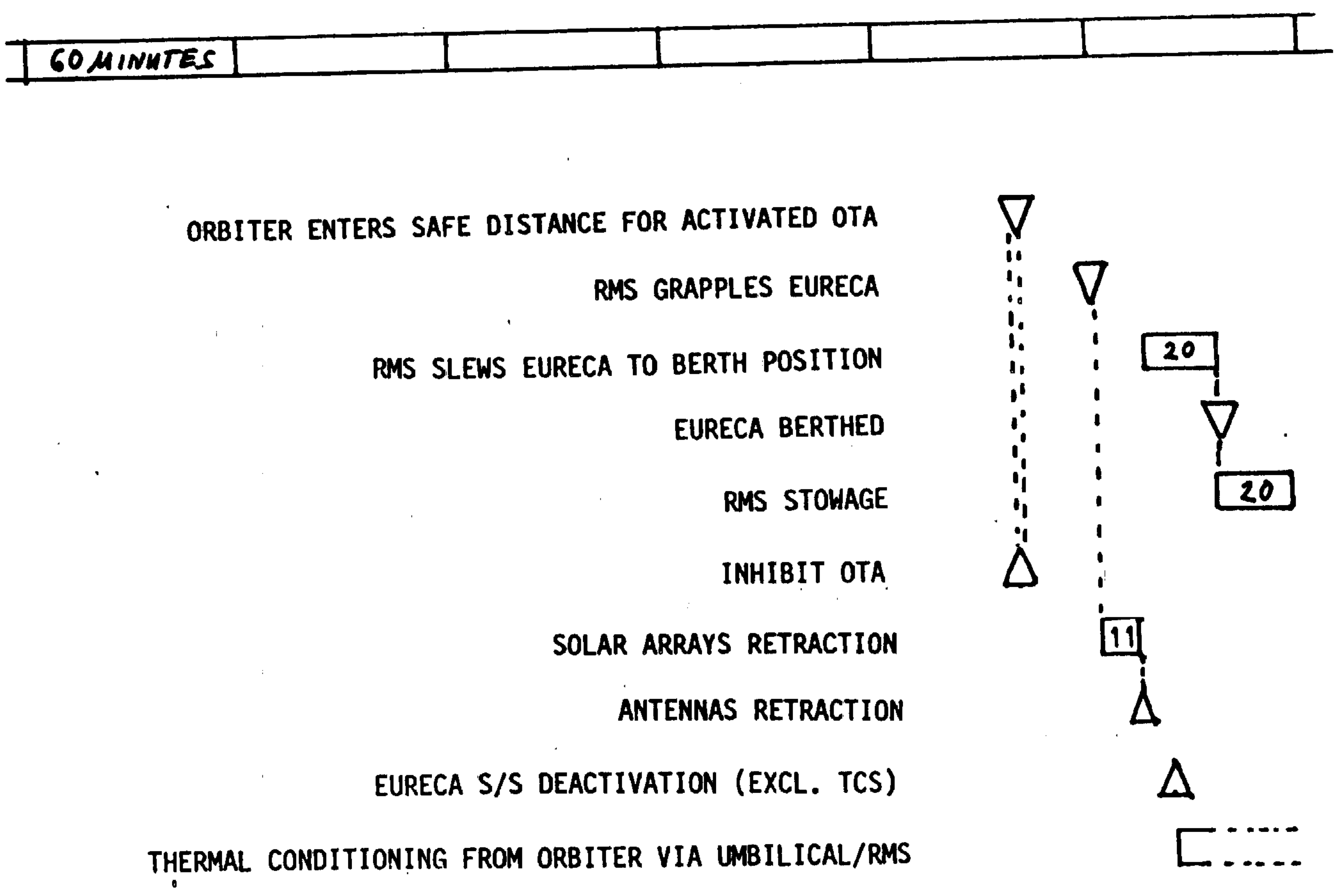
THE EURECA FINE ACS WILL REMAIN ACTIVE UNTIL THE RMS GRAPPLES EURECA. ONCE EURECA IS GRAPPLED BY THE RMS EURECA SYSTEMS WILL CONTINUE TO BE DEACTIVATED BY RF COMMANDS.

ALL MONITORING AND CONTROL FUNCTIONS FOR RETRIEVAL WILL BE PERFORMED FROM ESOC VIA MISSION CONTROL CENTER HOUSTON (MCC-H) AND ORBITER PI RF LINK.

PAYLOAD-RELATED ACTIVITIES SHALL BE LIMITED TO THE 3 HR IMMEDIATELY FOLLOWING GRAPPLE; THIS INCLUDES ALL STOWING AND SECURING.

EUROPEAN RETRIEVABLE CARRIER (EURECA)

EURECA DEACTIVATION DURING RETRIEVAL



EURECA PROXIMITY OPERATIONS ISSUES

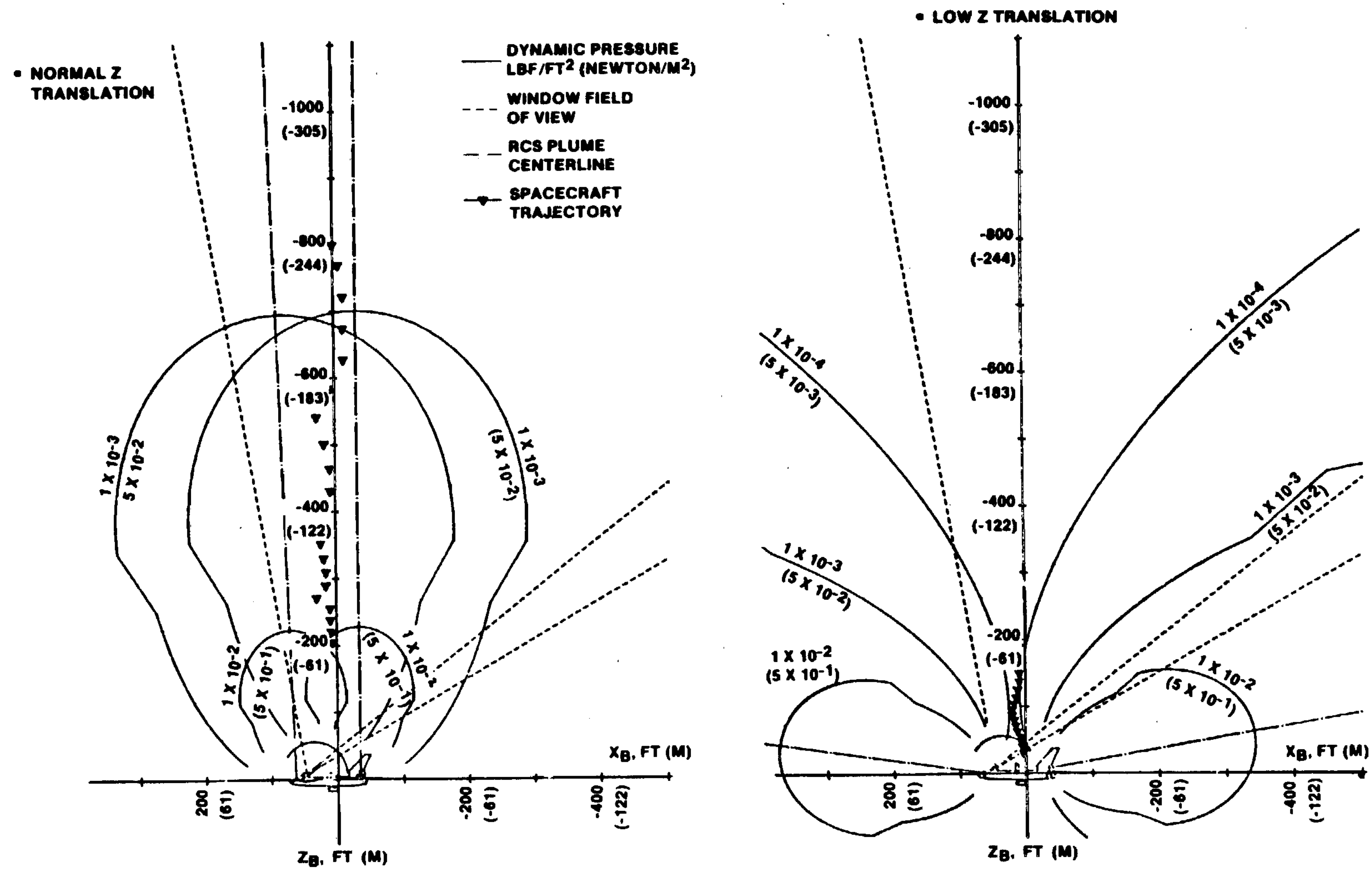
EURECA
EUropean REtrievable CArrier

- O SPECIFICATION OF AN ACCEPTABLE CONTROL BOX (STATE ERROR, STATE UNCERTAINTY)
- O SAFE DISTANCE FOR SOLAR ARRAY, ANTENNA DEPLOYMENT / RETRACTION
  - o EURECA PREFERENCE FOR DEPLOY/RETRACT AT THE RMS
  - o POTENTIAL HAZARD BEEING ASSESSED BY NASA OPERATIONS
    - CLEARANCE ENVELOPE, RELATIVE SPACECRAFT ORIENTATION
    - PLUME IMPLINGEMENT/EURECA CONTROL STABILITY
  - o STRUCTURAL LOADS/TORQUES INDUCED BY RMS AND POTENTIAL PLUME IMPINGEMENT ON SOLAR ARRAY ANALYSED BY ESA
  - o PREFERENCE FOR SOLAR ARRAYS EDGE TO ORBITER :

    EURECA X PARALLEL TO ORBITER Y
    EURECA Y PARALLEL TO ORBITER Z
    EURECA Z PARALLEL TO ORBITER X
  - o REQUIREMENT FOR LOW-Z 0,2 FT/SEC FINAL BRAKING BURN BEFORE GRAPPLE (RESULTS IN APR. 0.3 LB-SEC TRANSLATION IMPULSE AND 0.08 FT-LB-SEC TORQUE IMPULSE IN 60 FT DISTANCE).
- O ESTABLISH DETAILED APPROACH-TO-GRAPPLE TIMELINE AND PROFILE
- O PROVISION OF ACCURATE EURECA STATE VECTOR (POSITION, VELOCITY) BASED ON IMPROVED ORBITER NAVIGATIONAL ACCURACIES AND RADAR TRACKING DURING DEPLOYMENT/SEPARATION.

EXHAUST PLUME EXPOSURE DURING APPROACH

EURECA
EUropean REtrievable CArrier



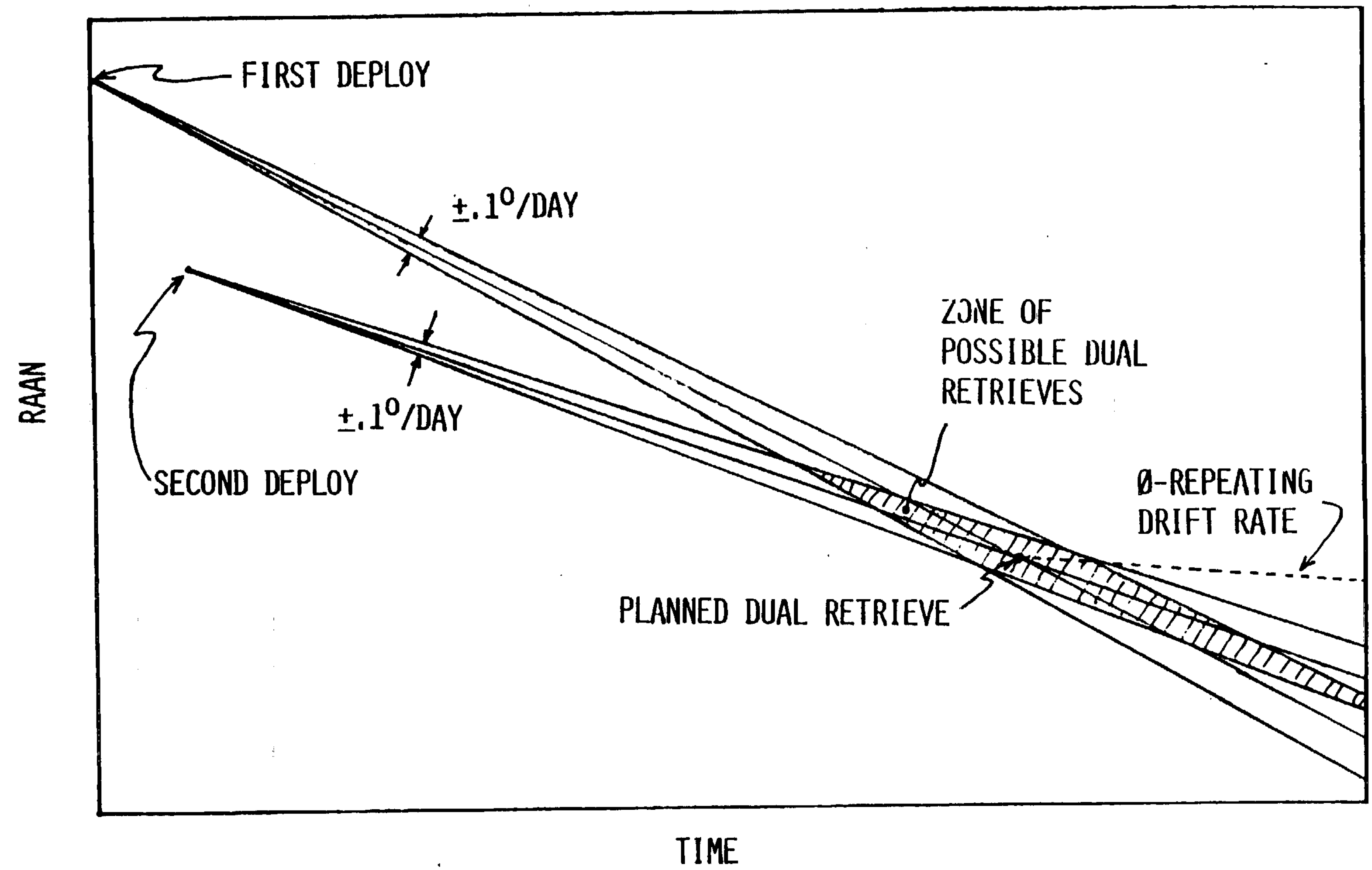
USER FRIENDLY IMPROVEMENTS OF PRESENT STANDARD RETRIEVAL POLICY/REQUIREMENTS.

EURECA
EUropean REtrievable CArrier

- CUSTOMER TO SPECIFY RAAN (FOR SINGLE RENDEZ-VOUS PER FLIGHT)
  - ALLOWS FIRM PLANNING OF INITIAL ORBITAL ALTITUDE, OVERALL MISSION PROFILE, AND REDUCES PLATFORM PROPELLANT REQUIREMENT AND MANOEUVER COMPLEXITY.
- REDUCE RETRIEVAL PERIOD OF 90 DAYS
  - INCREASED RETRIEVAL SCHEDULE RELIABILITY REQUIRED FOR MICROGRAVITY MISSIONS (EXPERIMENTAL AND COMMERCIAL)
  - SCHEDULE RELIABILITY WILL SIGNIFICANTLY IMPROVE COST EFFECTIVENESS OF OVERALL PLATFORM DESIGN AND OPERATION.
- REDUCE TIME BETWEEN CONTROL BOX START TIME AND COMMENCEMENT OF RETRIEVAL SERVICES
  - ALLOWS MORE TIME FOR PLATFORM TRIM-TRACK-TRIM SEQUENCES TO IMPROVE CONTROL BOX PARAMETERS.
  - PLATFORM TRANSLATION AND TRAJECTORY CONTROL WITHIN TBD CONTROL ZONE CAN EASE RENDEZ-VOUS OPERATIONS OF THE STS ORBITER AND WOULD BE APPLICABLE FOR SPACE STATION PROXIMITY OPERATIONS.

EURECA
EUropean REtrievable CArrier

RATIONALE FOR INITIAL TARGET STATE RAAN HISTORY FOR DUAL RENDEZVOUS



USER FRIENDLY IMPROVEMENTS OF PRESENT STANDARD RETRIEVAL POLICY/REQUIREMENTS (cont'd)

EURECA
EUropean REtrievable CArrier

- REDUCE 6 TO 9 MONTHS REFLIGHT INTERVAL
  - PRESENT REFLIGHT POLICY RESULTS FROM STANDARD NSTS MANIFESTING CAPABILITY FOR DEPLOYMENT MISSIONS, BUT IS NOT RESPONSIVE TO THE NEEDS OF RETRIEVAL PAYLOADS PARTICULARLY OF MICROGRAVITY INSTRUMENTS.
  - NSTS CAPABILITY FOR EARLIER RETRIEVAL REFLIGHT WILL SIGNIFICANTLY IMPROVE COST EFFECTIVENESS OF PLATFORM DESIGN AND OPERATIONS.

- ESTABLISH A USER ATTRACTIVE RETRIEVAL POLICY FOR THE 260 NMI ORBIT.
  - COMMENSURATE WITH GROWING DEPLOYMENT/SERVICING/RETRIEVAL MARKET AT 260 NMI ALTITUDE
  - EURECA CAPABILITIES ADEQUATE TO ACCOMMODATE A HIGHER ALTITUDE CONCEPT.
  - WILL IMPROVE FUEL EFFICIENCY OF PLATFORMS (LESS LAUNCH MASS OR HIGHER ORBIT/LONGER ON-ORBIT STAYTIME) AND ENSURE BETTER CONDITIONS FOR POTENTIAL REFLIGHT.

EURECA
EUropean REtrievable CArrier

EURECA AND SPACE STATION OPERATIONS

EURECA IN THE SPACE STATION SCENARIO

EURECA
EUropean REtrievable CArrier

- THE EURECA PLATFORM CAN OPERATE AS A COMPLEMENTARY EXTENSION OF THE SPACE STATION MANNED CORE CAPABILITIES. EURECA's SIZE AND RESOURCES CAPABILITIES ARE APPROPRIATE TO BE USEFUL FOR A LARGE RANGE OF POTENTIAL CUSTOMERS. ITS SIZE AND CAPABILITIES ARE CONSIDERED COMMENSURATE WITH FUNDING AND INSTRUMENT AVAILABILITY.

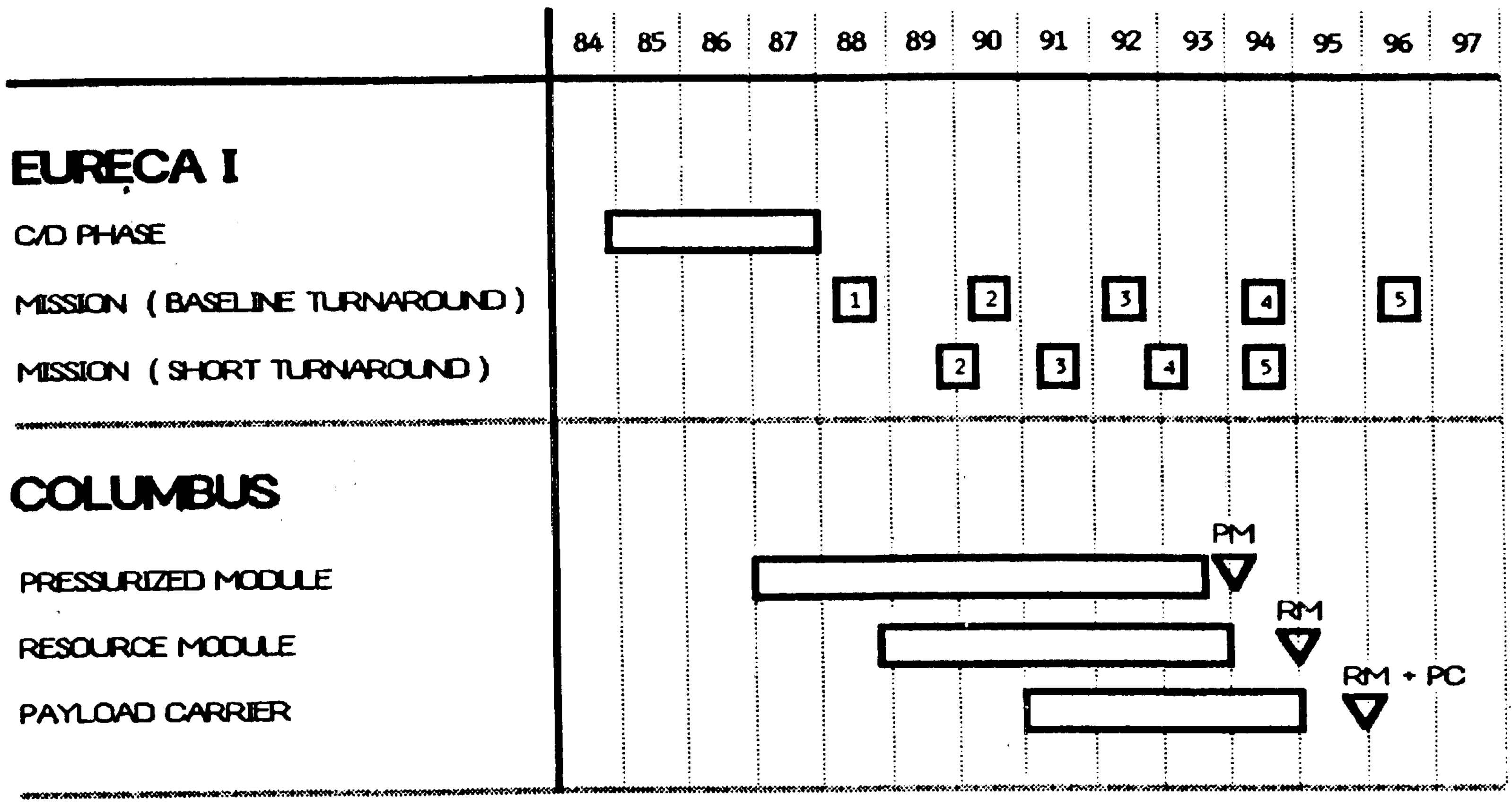
- EURECA MEETS ESSENTIAL FUNCTIONAL AND GENERAL DESIGN REQUIREMENTS FOR UNMANNED PLATFORMS IN THE SPACE STATION SCENARIO. ITS GROWTH CAPABILITY ALLOWS A STEP-BY-STEP ADAPTATION TO EVOLVING MISSION AND SPACE STATION/ PLATFORM SPECIFIC DESIGN REQUIREMENTS

- EURECA WILL BE AN IDEAL TEST BED FOR DEVELOPING AND DEMONSTRATING OPERATIONS AND SAFETY DESIGN REQUIRED FOR PLATFORM SPACE STATION OPERATIONS INCLUDING RENDEZ-VOUS AND PROXIMITY OPERATIONS AND SERVICING.

- SINCE IN-SITU SERVICING BY THE STS AS WELL AS SERVICING IN THE STATION PROXIMITY ZONE ARE VIABLE OPTIONS FOR CO-ORBITING AND NON-CO-ORBITING PLATFORMS THE ASSOCIATED TECHNIQUES AND PROCEDURES CAN BE DEMONSTRATED DURING EURECA MISSIONS WELL IN ADVANCE OF THE SPACE STATION AND AT LOW COST.

EURECA IN THE SPACE STATION SCENARIO

EURECA
EUropean REtrievable CArrier



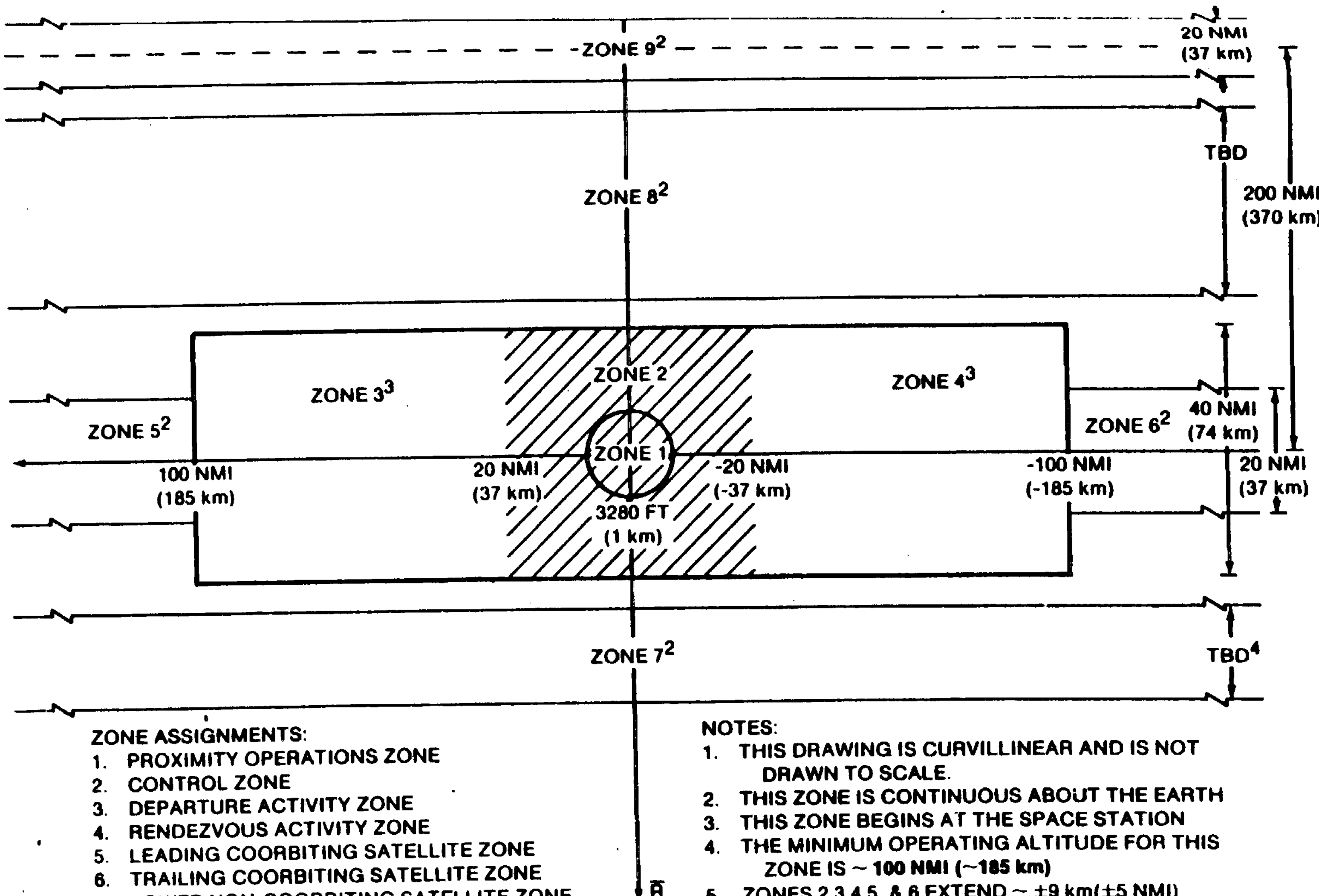
SPACE STATION RENDEZ-VOUS AND PROXIMITY OPERATIONS.

EURECA
EUropean REtrievable CArrier

- SEVERAL DETACHED PLATFORM OPERATIONS WILL INTERACT DIRECTLY WITH THE STATION (RENDEZ-VOUS, PROX OPS MANOEUVERS, INSPECTION OR IN-SITU SERVICING)
- THE CONCEPT OF OPERATIONAL ZONES ALLOWS EARLY DEFINITION OF REQUIREMENTS INCLUDING COMMUNICATION AND TELEMETRY AS WELL AS COMMAND/CONTROL/ TRACKING.
- OPERATIONAL ZONES SHOULD BE SPECIFIED SUCH AS TO ALLOW CLEAR DIVISION OF RESPONSIBILITIES BETWEEN STATION AND PLATFORM CONTROL CENTERS, TO REDUCE THE LEVEL OF ROUTINE CREW INVOLVEMENT AND TO ALLOW STANDARDIZATION OF FLIGHT PLANNING AND OPERATIONS.
- OUTSIDE THE PROX OPS ZONE AND THE CONTROL ZONE THE COMMAND/CONTROL OF CO-ORBITING AND NON-CO-ORBITING PLATFORMS SHALL BE MAINTAINED BY THEIR GROUND CONTROL CENTERS.
- WITHIN THE CONTROL ZONE AND THE PROX OPS ZONE PRECISION CONTROL OF THE PLATFORM TRAJECTORY AND TRAJECTORY DYNAMICS SHALL BE PERFORMED AUTOMATICALLY WITH MONITORING AND TRACKING BY THE SPACE STATION.
- OPERATIONS OF PLATFORMS IN THE VICINITY OF THE SPACE STATION REQUIRE DETAILED OPERATIONS AND SAFETY ANALYSIS AND HIGH PRIORITY MUST BE GIVEN TOWARDS MATURING THE CONCEPT OF OPERATIONAL ZONES.

SPACE STATION OPERATIONAL CONTROL ZONES

EURECA
EUropean REtrievable CArrier



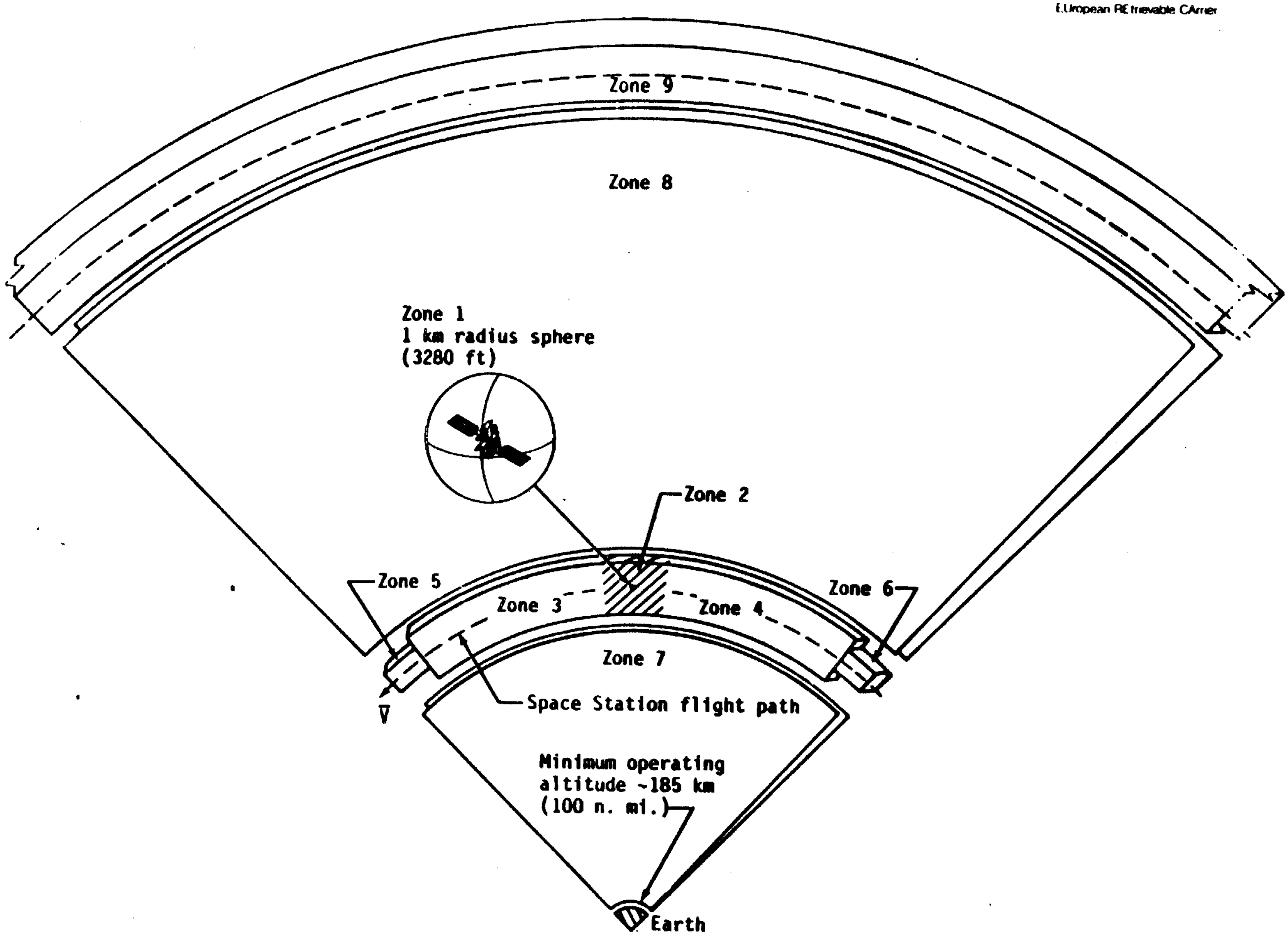
ZONE ASSIGNMENTS:

1. PROXIMITY OPERATIONS ZONE
2. CONTROL ZONE
3. DEPARTURE ACTIVITY ZONE
4. RENDEZVOUS ACTIVITY ZONE
5. LEADING COORBITING SATELLITE ZONE
6. TRAILING COORBITING SATELLITE ZONE
7. LOWER NON-COORBITING SATELLITE ZONE
8. UPPER NON-COORBITING SATELLITE ZONE
9. PARKING ORBIT ZONE

NOTES:

1. THIS DRAWING IS CURVILLINEAR AND IS NOT DRAWN TO SCALE.
2. THIS ZONE IS CONTINUOUS ABOUT THE EARTH
3. THIS ZONE BEGINS AT THE SPACE STATION
4. THE MINIMUM OPERATING ALTITUDE FOR THIS ZONE IS ~ **100 NMI (~185 km)**
5. ZONES 2,3,4,5, & 6 EXTEND ~ ±9 km(±5 NMI) OUT-OF-PLANE
6. ZONES 7,8 AND 9 ARE SPHERICAL SHELLS CENTERED ABOUT THE EARTH

SPACE STATION OPERATIONAL CONTROL ZONES



EURECA
European REtrievable CArrier

EURECA AND SPACE STATION

- THE SPACE STATION WILL BE AN ATTRACTIVE TRANSPORTATION NODE FOR EURECA MISSIONS
  - INCREASED SCHEDULE RELIABILITY
  - TRAFFIC WILL ALLOW COST EFFECTIVE RETRIEVAL AT HIGHER ALTITUDE
- SPACE STATION TRAFFIC WILL RENDER SELECTED SERVICING OPTIONS FOR EURECA MORE ATTRACTIVE (E.G. IN-SITU BY NSTS), I.E. REFUELING AND REPLACEMENT OF LIFE-LIMITED ITEMS.
- THE EURECA BASELINE IS COMPATIBLE WITH THE SPACE STATION AS TRANSPORTATION NODE
- PRECISION CONTROL OF EURECA'S TRAJECTORY AND TRAJECTORY DYNAMICS (GN&C) CAN BE GRADUALLY IMPROVED AND CAN BE DEMONSTRATED DURING NORMAL EURECA/STS RETRIEVAL MISSIONS
- FULL COMPATIBILITY WITH SPACE STATION DESIGN, OPERATION AND TRAFFIC ZONE REQUIREMENTS CAN BE VERIFIED WELL IN ADVANCE OF THE SPACE STATION IOC BY TEST IN A REALISTIC OPERATIONAL ENVIRONMENT.

EURECA AND SPACE STATION (CONT'D)

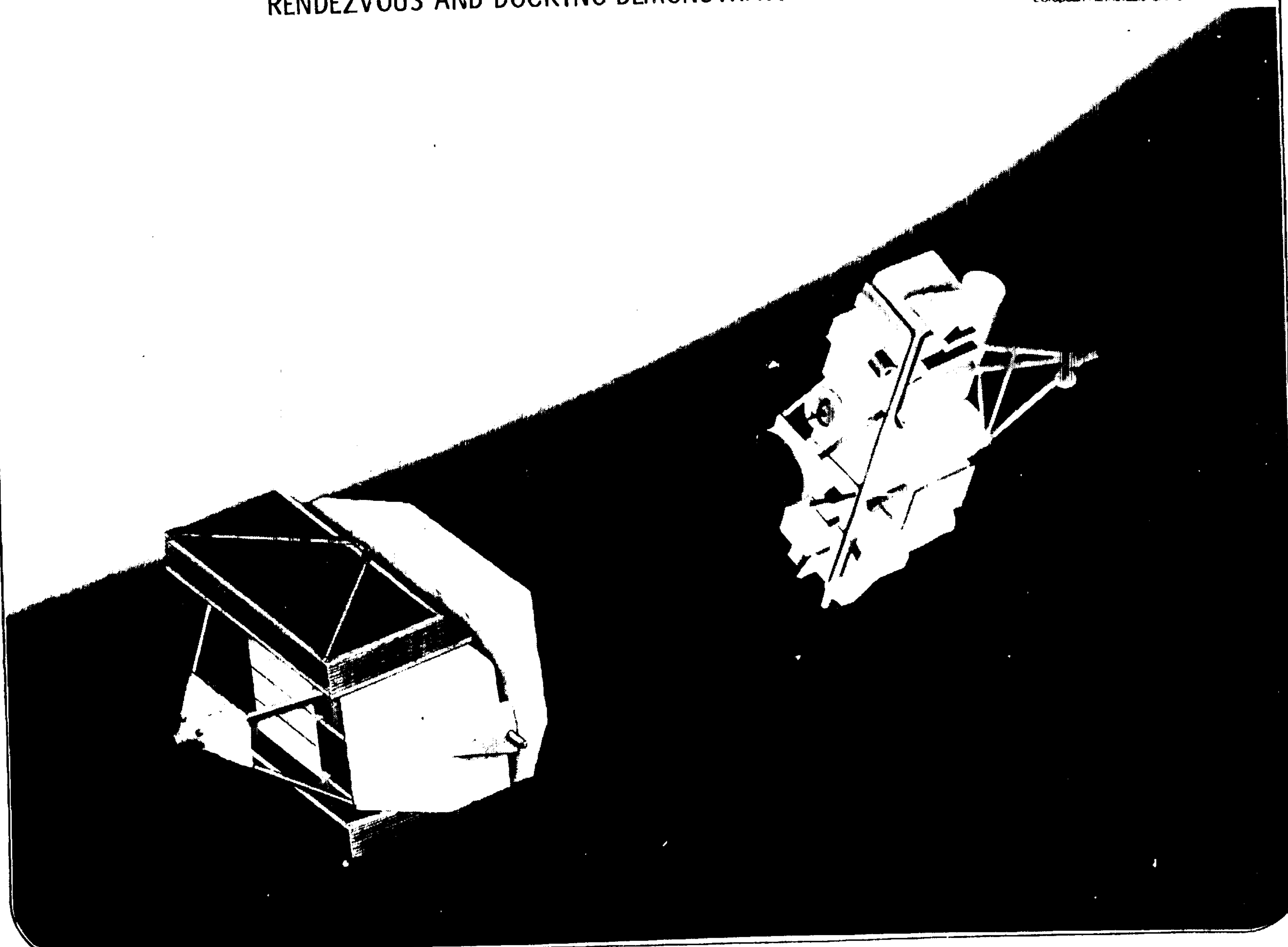
EURECA
EUropean REtrievable CArrier

0 EURECA CAN BE CONSIDERED AS AN OPERATIONAL TEST BED TO DEMONSTRATE THE VIABILITY OF THE TETHERED SATELLITE SYSTEM AS A REMOTE DOCKING PORT FOR THE SPACE STATION TO REDUCE THE POTENTIAL OF COLLISION DURING PROXIMITY OPERATIONS.

0 WITHIN THE EUROPEAN PLATFORM SCENARIO EURECA IS BEING CONSIDERED SINCE SOME TIME AS A TEST BED FOR DEMONSTRATING HARDWARE AND OPERATIONS REQUIRED FOR AUTOMATED RENDEZVOUS AND DOCKING.

RENDEZVOUS AND DOCKING DEMONSTRATION

EURECA
EUropean REtrievable CArrier



SUMMARY

EURECA
EUropean REtrievable CArrier

- O EURECA RETRIEVAL MISSIONS WILL HAVE A PILOT FUNCTION IN ESTABLISHING AND DEMONSTRATING ROUTINE RENDEZ-VOUS AND PROXIMITY OPERATIONS CAPABILITY DURING SHARED DEPLOYMENT/ RETRIEVAL MISSIONS

- O EURECA/STS RENDEZ-VOUS AND PROXIMITY OPERATIONS CAN FURTHER BE DEVELOPED AND IMPROVED IN DIRECT SUPPORT OF FUTURE SPACE-STATION OPERATIONS

- O EURECA IS COMPATIBLE WITH THE SPACE STATION AS A TRANSPORATION AND SERVICING NODE

- O EURECA CAN BE ADAPTED FOR ADVANCED PROXIMITY OPERATIONS IN CORRECT PHASING WITH EVOLVING SPACE STATION/PLATFORM REQUIREMENTS.

SPARTAN RENDEZVOUS

Scott Lambros
Goddard Space Flight Center
February 19, 1985

SPARTAN IS:

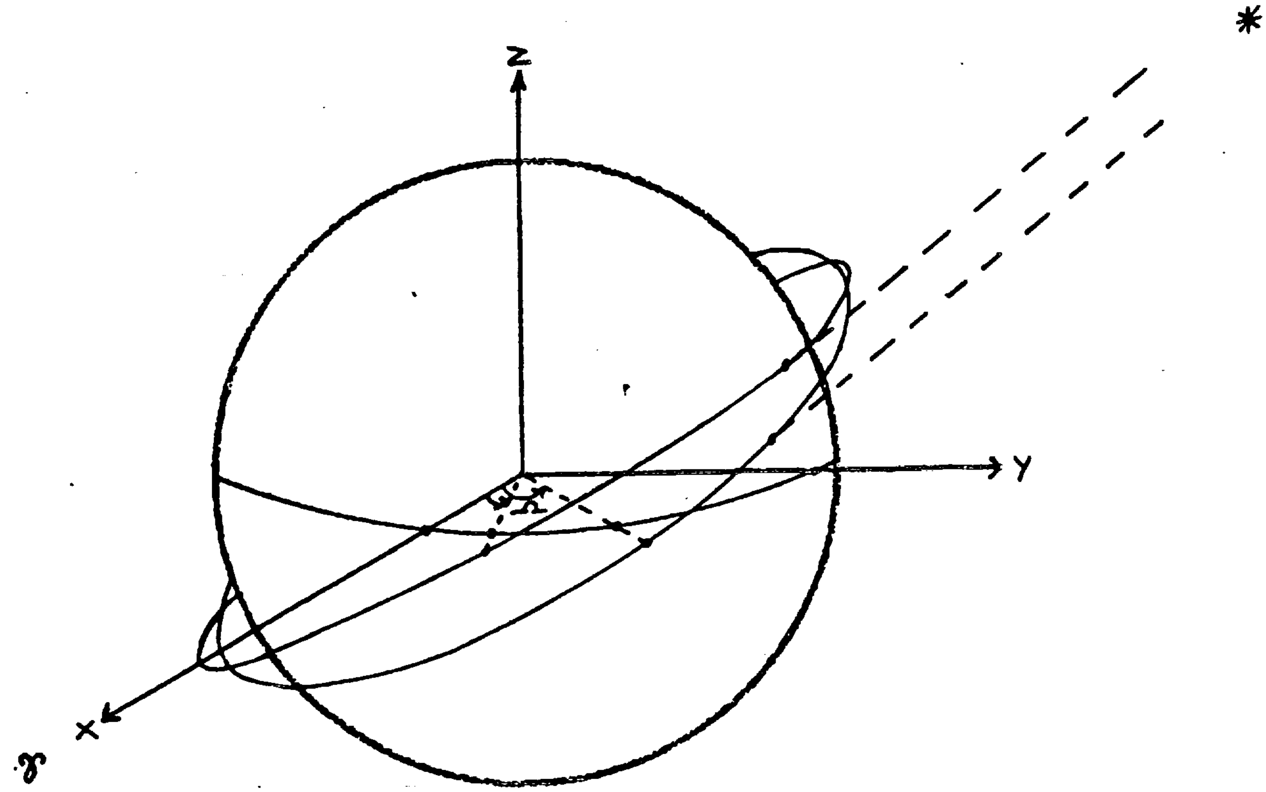
- o A FLEET OF SMALL FREE-FLYING PAYLOADS
- o LOW COST
- o AUTONOMONS - NO COMMAND OR TELEMETRY LINK
  (THE MISSION MANEUVERING SEQUENCE IS ALL PREPROGRAMMED)
- o AN EXPERIMENT CARRIER FOR ASTROPHYSICS SCIENCE INSTRUMENTS

SPARTAN WILL:

- o CARRY SOUNDING ROCKET TYPE PAYLOADS
- o BE DEPLOYED FROM AND THEN RETRIEVED BY THE SHUTTLE
- o HAVE A TOTAL MISSION TIME IN THE NEIGHBORHOOD OF 40-48 HOURS (THE SPARTAN PROJECT WAS RESPONSIBLE FOR HAVING A STATE VECTOR PROVIDED TO JSC IN ORDER TO RECEIVE MORE THAN 8 HOURS OF MISSION TIME)

BECAUSE SPARTAN IS PREPROGRAMMED:

- MUST PLAN FOR A RANGE OF ORBITS - WILL NOT KNOW THE EXACT ORBIT BECAUSE IT MAY SHIFT DUE TO A LAUNCH SLIP.
- TARGETS ARE ONLY VIEWABLE FOR A 'CORE' TIME, I.E., A TIME WHEN THEY ARE VISIBLE FOR THE WHOLE RANGE OF POSSIBLE ORBITS.
- SETTING THE POSITION OF THE GRAPPLE FIXTURE PERPENDICULAR TO THE ORBIT PLANE FOR RENDEZVOUS IS NOT POSSIBLE FOR ALL DIFFERENT ORBITS.



ORBIT CHANGES:

-- AS THE SHUTTLE LAUNCH TIME OF DAY VARIES (ALONG WITH THE DAY OF LAUNCH), THE RIGHT ASCENSION OF ASCENDING NODE (Ω) VARIES. THIS RESULTS IN TARGETS BEING VISIBLE TO SPARTAN AT DIFFERENT TIMES IN THE ORBIT.

SPARTAN - SHUTTLE SEPARATION DUE TO ATMOSPHERIC DRAG

o ASSUMPTIONS:

- SHUTTLE MASS = 90,700 KG.
- MIN AREA = 64.1 M^2
- MAX AREA = 367 M^2
- SPARTAN MASS = 825.4 KG.
- MIN AREA = 1.45 M^2
- MAX AREA = 2.73 M^2
- ATMOSPHERE MODEL IS HARRIS-PRIESTER
- ORBIT: CIRCULAR, INCLINATION = 28.5°

o METHOD USED:

ORBIT PROPAGATOR (NUMERICAL INTEGRATOR) USED TO GENERATE AN EPHEMERIS OF THE 2 SPACECRAFT POSITIONS (STATE VECTORS). THE DIFFERENCE BETWEEN THE 2 WAS THEN CALCULATED AT THE APPROPRIATE HOURLY INCREMENTS. AN ANALYTIC METHOD WAS ALSO USED TO VERIFY THE NUMBERS.

o AT THE END OF 40 HOURS THE SEPARATION DISTANCE CAN BE QUITE HIGH.

SEPARATION FROM DRAG-FREE BODY (KM) :

ELAPSED TIME (HRS):		0	6	12	18	24	30	36	40
SPARTAN	MIN DRAG	0	2.5	9.8	22.1	39.3	61.5	88.7	107.8
	MAX DRAG	0	4.7	18.5	41.7	74.3	116.3	168.0	208.0
ORBITER	MIN DRAG	0	1.0	3.9	8.9	15.8	24.7	35.6	44.1
	MAX DRAG	0	5.7	22.7	51.0	91.0	142.6	206.0	255.1

SPARTAN SEPARATION FROM ORBITER (KM) :
ALT. = 300 KM (~162 NMI)

ELAPSED TIME (HRS):		0	6	12	18	24	30	36	40
ORBITER MIN;	SPARTAN MIN	0	1.5	5.9	13.2	23.5	36.8	53.1	65.7
	SPARTAN MAX	0	3.7	14.6	32.8	58.5	91.6	132.4	164.0
ORBITER MAX;	SPARTAN MIN	0	-3.2	-12.9	-29.0	-51.7	-81.1	-117.3	-145.3
	SPARTAN MAX	0	-1.0	-4.2	-9.4	-16.7	-26.2	-38.0	-47.1

'+' MEANS SPARTAN IS AHEAD
'-' MEANS ORBITER IS AHEAD

SPARTAN SHUTTLE SEPARATION DUE TO ATMOSPHERIC DRAG AT DIFFERENT ALTITUDES 120NMI. AND 200 NMI.

- ALTITUDE HAS A LARGE EFFECT ON THE SEPARATION DISTANCE

- THE SEPARATION OF THE SPARTAN AND SHUTTLE IN ALTITUDE AFTER 40 HOURS IS VERY LITTLE: ABOUT 1 KM FOR THE 300 KM ALT. CASE, 11 KM FOR THE 222 KM ALT. CASE, AND 0.5 KM FOR THE 370 KM ALT. CASE.

SPARTAN SEPARATION FROM ORBITER (KM) :
ALT. = 222 KM (~120 NMI)

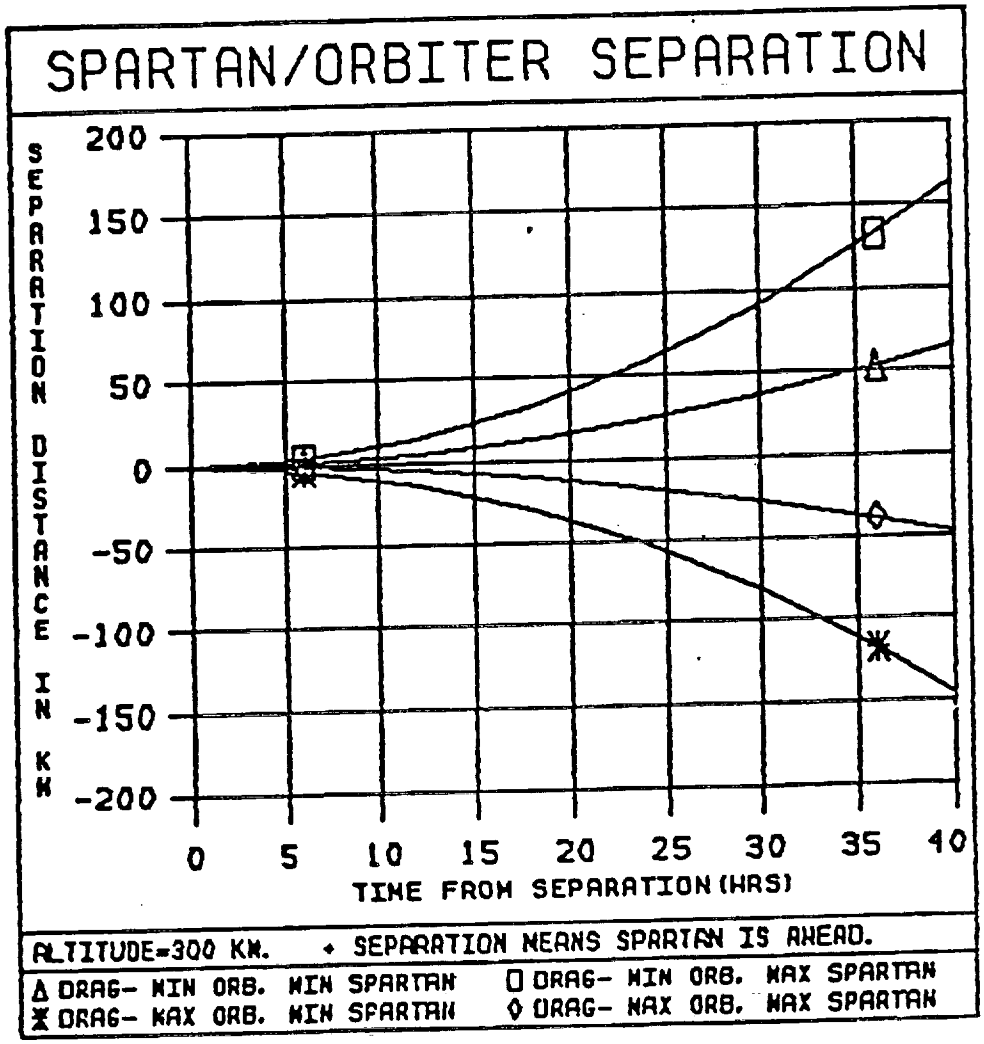
ELAPSED TIME (HRS):		0	6	12	18	24	30	36	40
ORBITER MIN;	SPARTAN MIN	0	8.8	35.5	80.7	145.1	229.6	335.0	416.3
	SPARTAN MAX	0	22.0	89.2	204.3	370.2	590.4	868.3	1085.6
ORBITER MAX;	SPARTAN MIN	0	-19.5	-79.7	-184.2	-336.8	-542.1	-805.8	-1015.
	SPARTAN MAX	0	-6.3	-26.0	-60.6	-111.7	-181.4	-272.3	-345.9

SPARTAN SEPARATION FROM ORBITER (KM) :
ALT. = 370 KM (~200 NMI)

ELAPSED TIME (HRS):		0	6	12	18	24	30	36	40
ORBITER MIN;	SPARTAN MIN	0	0.4	1.7	3.9	6.9	10.8	15.6	19.4
	SPARTAN MAX	0	1.1	4.3	9.6	17.1	26.8	38.8	48.1
ORBITER MAX;	SPARTAN MIN	0	-1.0	-3.8	-8.5	-15.1	-23.7	-34.2	-42.5
	SPARTAN MAX	0	-0.3	-1.2	-2.7	-4.9	-7.6	-11.1	-13.7

'+' MEANS SPARTAN IS AHEAD
'-' MEANS ORBITER IS AHEAD

SYNOPSIS OF SPARTAN - SHUTTLE SEPARATION DISTANCE RESULTS


SPARTAN/ORBITER SEPARATION
SEPARATION DISTANCE IN KM
200
150
100
50
0
-50
-100
-150
-200
0
5
10
15
20
25
30
35
40
TIME FROM SEPARATION (HRS)
ALTITUDE=300 KM.
+ SEPARATION MEANS SPARTAN IS AHEAD.
△ DRAG- MIN ORB. MIN SPARTAN
□ DRAG- MIN ORB. MAX SPARTAN
✱ DRAG- MAX ORB. MIN SPARTAN
◊ DRAG- MAX ORB. MAX SPARTAN

SPARTAN ORBIT LIFETIMES

- o FOR THE FUTURE POSSIBILITY OF DEPLOYING A SPARTAN ON ONE SHUTTLE MISSION, AND RETRIEVING IT ON THE NEXT SHUTTLE MISSION

- o ASSUMPTIONS:
  - CIRCULAR ORBIT
  - INCLINATION = 28.5°
  - $\frac{\text{COEFFICIENT OF DRAG X AREA}}{\text{MASS}}$ = .009 AND .068

    AS A MINIMUM AND A MAXIMUM FOR THIS SPARTAN CONFIGURATION.
  - SOLAR FLUX VALUES USED WERE 100, 175, AND 250
  - INITIAL ALTITUDE RANGE FROM 250 - 600 KM

TIME ABOVE 250 KM. IN DAYS

ALTITUDES WERE CHECKED AT 5 DAY INTERVALS. DAYS GIVEN IS THE LAST CHECKED BEFORE THE ALTITUDE FELL BELOW 250 KM.

*** ALT = 250 KM ***

COEF =	.009	.068
FLUX = 100	0	0
175	0	0
250	0	0

*** ALT = 300 KM ***

COEF =	.009	.068
FLUX = 100	205	25
175	110	10
250	80	10

*** ALT = 350 KM ***

COEF =	.009	.036	.068
FLUX = 100	365+	255	125
175	365+	120	50
250	270	70	35

*** ALT = 400 KM ***

COEF =	.009	.068
FLUX = 100	365+	365+
175	365+	145
250	365+	90

*** ALT = 450 KM ***

COEF =	.009	.068
FLUX = 100	365+	365+
175	365+	340
250	365+	195

*** ALT = 500 KM ***

COEF =	.009	.068
FLUX = 100	365+	365+
175	365+	365+
250	365+	365+

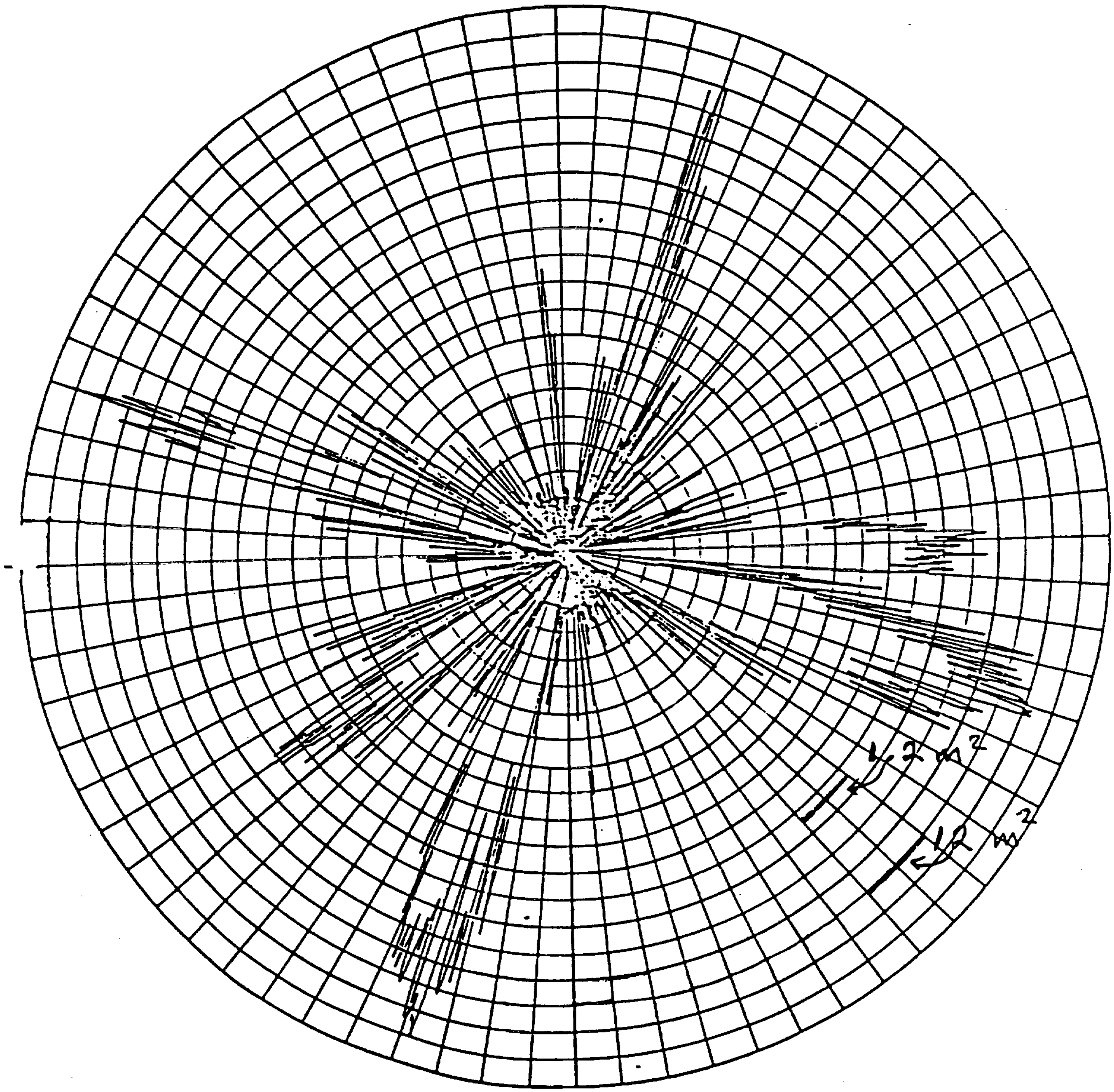
*** ALT = 600 KM ***

COEF =	.009	.068
FLUX = 100	365+	365+
175	365+	365+
250	365+	365+

MEASURING THE RADAR CROSS SECTION (RCS) OF SPARTAN:

- o GRAPH OF AMOUNT OF RADAR SIGNAL RETURNED
- o WITHOUT CORNER REFLECTORS
- o INCIDENCE ANGLE TO THE RADAR SOURCE VARIES FROM 0 TO 360 DEGREES:
  - THE FOUR HIGHEST PEAKS ARE THE FLAT SIDES
  - THE LOW SPOTS IN BETWEEN ARE THE CORNERS
- o NOT ENOUGH RCS TO BE SKIN TRACKED EITHER BY KU-BAND (SHUTTLE RADAR) OR C-BAND (GROUND RADAR).
- o A KU-BAND TRANSPONDER WOULD MAKE SPARTAN TRACKABLE BY THE SHUTTLE RADAR. HOWEVER, ONE CURRENTLY DOES NOT EXIST AND THE DEVELOPMENT COSTS ARE PROHIBITIVE TO SPARTAN.

SPARTAN RADAR CROSS SECTION MEASUREMENTS
WITHOUT CORNER REFLECTORS

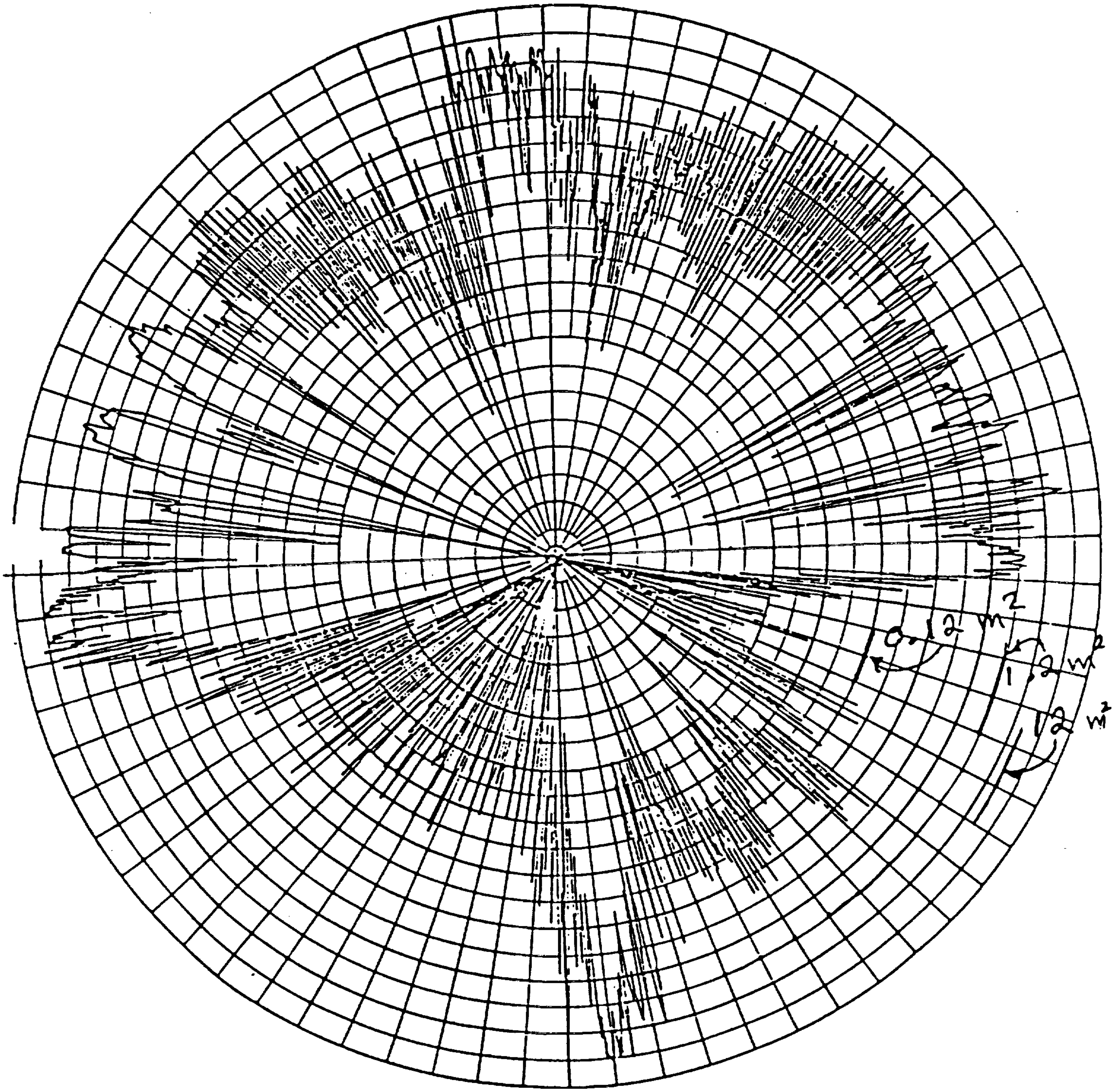


MEASURING THE RADAR CROSS SECTION (RCS) OF SPARTAN (CONTINUED):

- WITH CORNER REFLECTORS
- NULLS ARE FILLED IN BY USING THE CORNER REFLECTORS
- ENOUGH RCS TO BE TRACKED BY KU-BAND OR C-BAND.

SPARTAN RADAR CROSS SECTION MEASUREMENTS

WITH CORNER REFLECTORS



STATISTICS FOR SPARTAN RADAR CROSS SECTION:

- 9-INCH CORNER REFLECTORS WERE USED
- FREQUENCY IS 14 GHz - THIS IS THE SHUTTLE KU-BAND RADAR FREQUENCY
- THE INCIDENCE ANGLE IS MEASURED BY TAKING ONE OF THE SPARTAN PRINCIPLE AXES AND ROTATING IT BY THE INDICATED AMOUNT AROUND ANOTHER PRINCIPLE AXIS
- FOR EACH INCIDENCE ANGLE SPARTAN IS ROTATED 360° IN THE THIRD AXIS - THIS IS WHERE THE PROBABILITIES COME FROM - BY SAMPLING THE RCS AS IT ROTATES THROUGH THE 360°.
- DECIBELS PER SQUARE METER (dBsm) IS A MEASURE OF SIGNAL RETURNED AGAINST A STANDARD MEASURE. FOR EX., A 10 dBsm TARGET RETURNS ENOUGH SIGNAL TO LOOK LIKE A 10 M^2 TARGET. SO YOU CAN SEE HOW THE CORNER REFLECTORS ENHANCE THE RCS OF A 1 X 1 X 1 M SPARTAN MODEL.

Simulation Results

Gross Satellite Dimensions 1 × 1 × 1 meters

Corner Reflector Dimensions (square) 9.0 inches

Frequency (GHz)	Incidence Angle Theta (deg)	Probability that the radar cross section in greater than		
		0.0 dBsm	5.0 dBsm	10.0 dBsm
14.0	10	1.0	1.0	1.0
	15	1.0	1.0	0.98
	20	1.0	0.99	0.98
	25	1.0	1.0	0.98
	30	0.99	0.99	0.97
	35	0.98	0.89	0.76
	40	1.0	0.99	0.96
	45	1.0	0.99	0.99
	50	0.99	0.99	0.99
	55	1.0	1.0	0.97
	60	1.0	1.0	1.0
	65	1.0	0.99	0.91
	70	1.0	1.0	1.0
	75	1.0	1.0	1.0
	80	1.0	1.0	1.0
	85	1.0	1.0	1.0
	90	1.0	1.0	1.0
Averages		0.99	0.99	0.97

STATISTICS FOR SPARTAN RADAR CROSS SECTION:

- 9-INCH CORNER REFLECTORS WERE USED
- FREQUENCY IS 5.625 GH_Z - THIS IS THE GROUND C-BAND RADAR FREQUENCY
- SPARTAN 1 CURRENTLY HAS 9-INCH ALUMINUM CORNER REFLECTORS. THIS PROVIDES A HIGH ENOUGH RCS TO BE TRACKED BY C-BAND FROM THE GROUND, OR BY KU-BAND FROM THE SHUTTLE AT DISTANCES LESS THAN 19 KM.

Gross Satellite Dimensions 1 × 1 × 1 meter

Corner Reflector Dimensions (square) 9.0 inches

Frequency (GHz)	Incidence Angle Theta (deg)	Probability that cross section is greater than		
		0.0 dBsm	5.0 dBsm	10.0 dBsm
5.625	10	0.97	0.93	0.83
	15	1.0	0.92	0.88
	20	1.0	0.98	0.86
	25	1.0	0.97	0.89
	30	0.77	0.47	0.0
	35	0.98	0.96	0.88
	40	1.0	0.99	0.97
	45	0.94	0.85	0.72
	50	0.97	0.93	0.91
	55	0.94	0.88	0.69
	60	1.0	0.98	0.90
	65	1.0	0.99	0.96
	70	1.0	0.99	0.97
	75	1.0	0.97	0.90
	80	0.83	0.65	0.19
	85	1.0	0.99	0.90
	90	1.0	1.0	0.89
Averages		9.96	0.91	0.78

JSC RENDEZVOUS PROFILE FOR SPARTAN 1

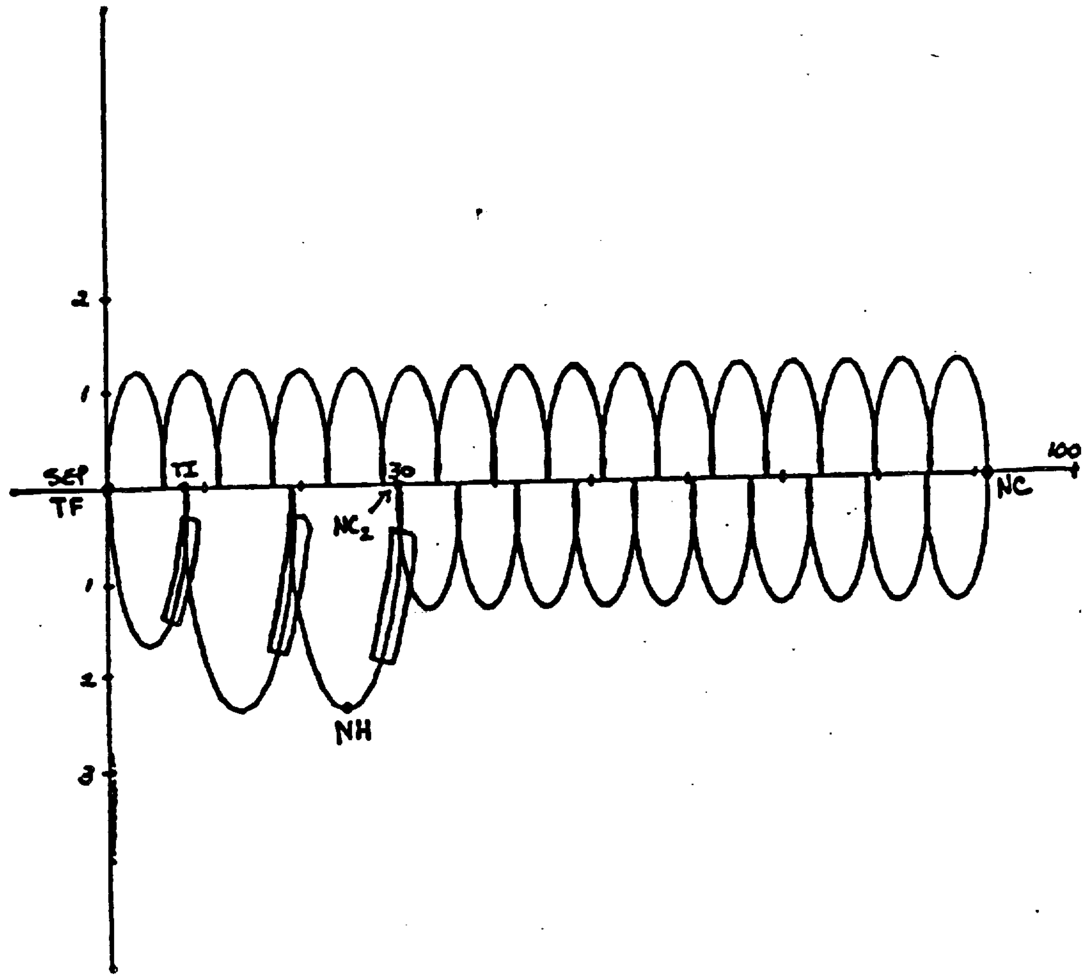
- THE SPARTAN PROJECT USES NASA C-BAND TRACKING NETWORK TO PROVIDE STATE VECTOR INFORMATION TO JSC. RENDEZVOUS BURNS, ETC., ARE DETERMINED AND CARRIED OUT BY JSC.

- SPARTAN CENTERED COORDINATE SYSTEM TRACKING THE MOTION OF THE SHUTTLE AS IT SEPARATES FROM SPARTAN.

- WITH A GROUND TRACK ON SPARTAN, THE SHUTTLE CAN SPEND ~1 DAY SEPARATING FROM IT, OUT TO ~90 NMI., THEN THE NEXT DAY COME BACK FOR RENDEZVOUS.

- ANY DRAG EFFECTS ARE TAKEN OUT WITH THE SHUTTLE BURNS.

SPARTAN RENDEZVOUS SCENARIO



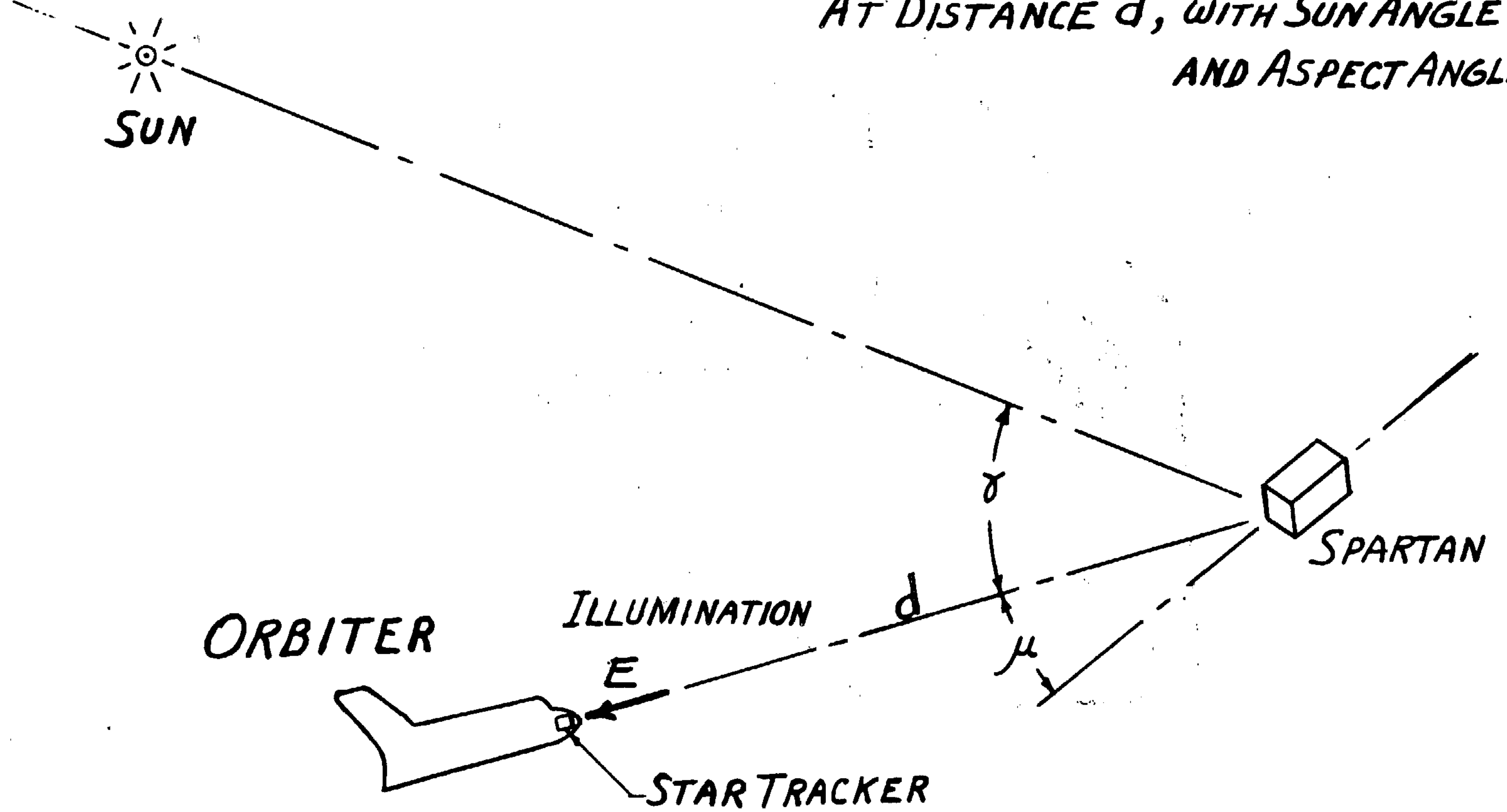
OPTICAL TRACKING

JOSEPH C. KING
GODDARD SPACE FLIGHT CENTER

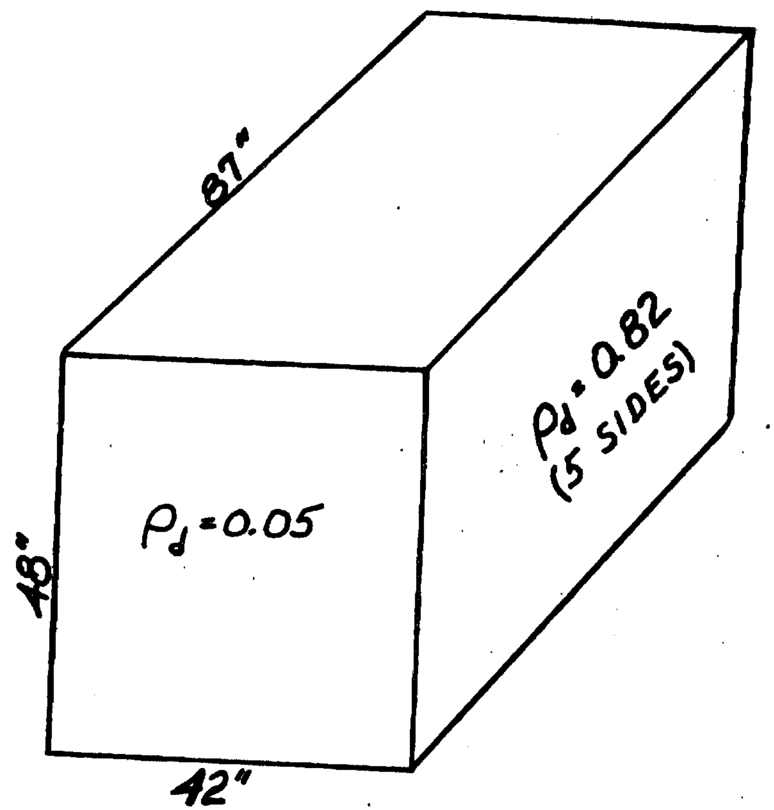
FEBRUARY 19, 1985

CAN ORBITER SEE SPARTAN?

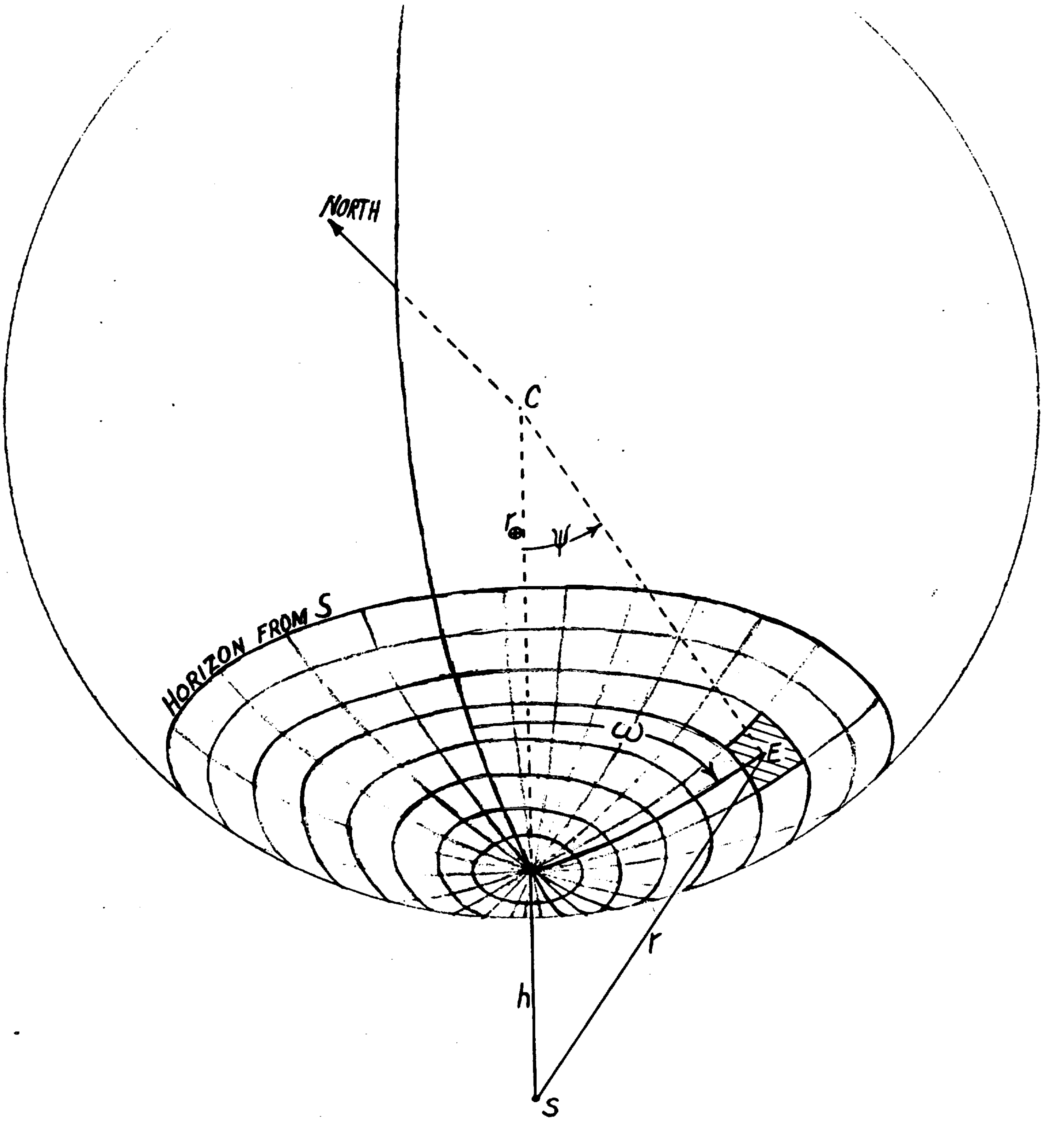
AT DISTANCE d, WITH SUN ANGLE γ
AND ASPECT ANGLE μ



②



SPARTAN REFLECTOR MODEL



ALBEDO INTEGRATION

4

SOLAR FLUX (TOTAL)

$$E = \underbrace{\left(\frac{F_\odot}{4\pi (AU)^2}\right)}_{\text{SOLAR ILLUM. ON PLATE (WEAR EARTH)}} \rho_d A \cos\eta \cos\mu / \pi d^2$$

DISTANCE OF OBSERVER FROM PLATE

REFLECTION, INCIDENCE } ANGLES

AREA OF PLATE

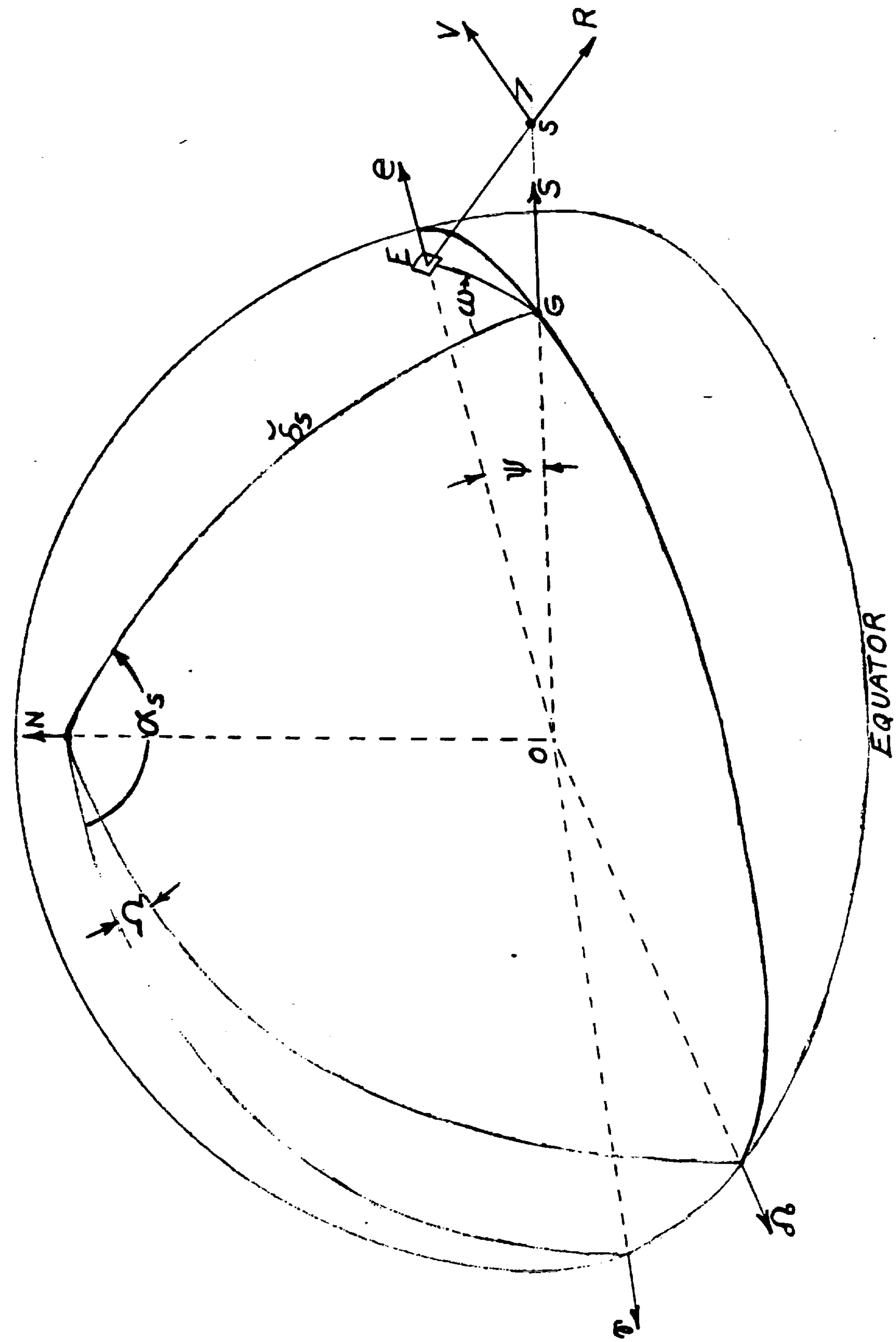
REFLECTANCE (DIFFUSE) OF SURFACE

SOLAR ILLUM. ON PLATE (WEAR EARTH)

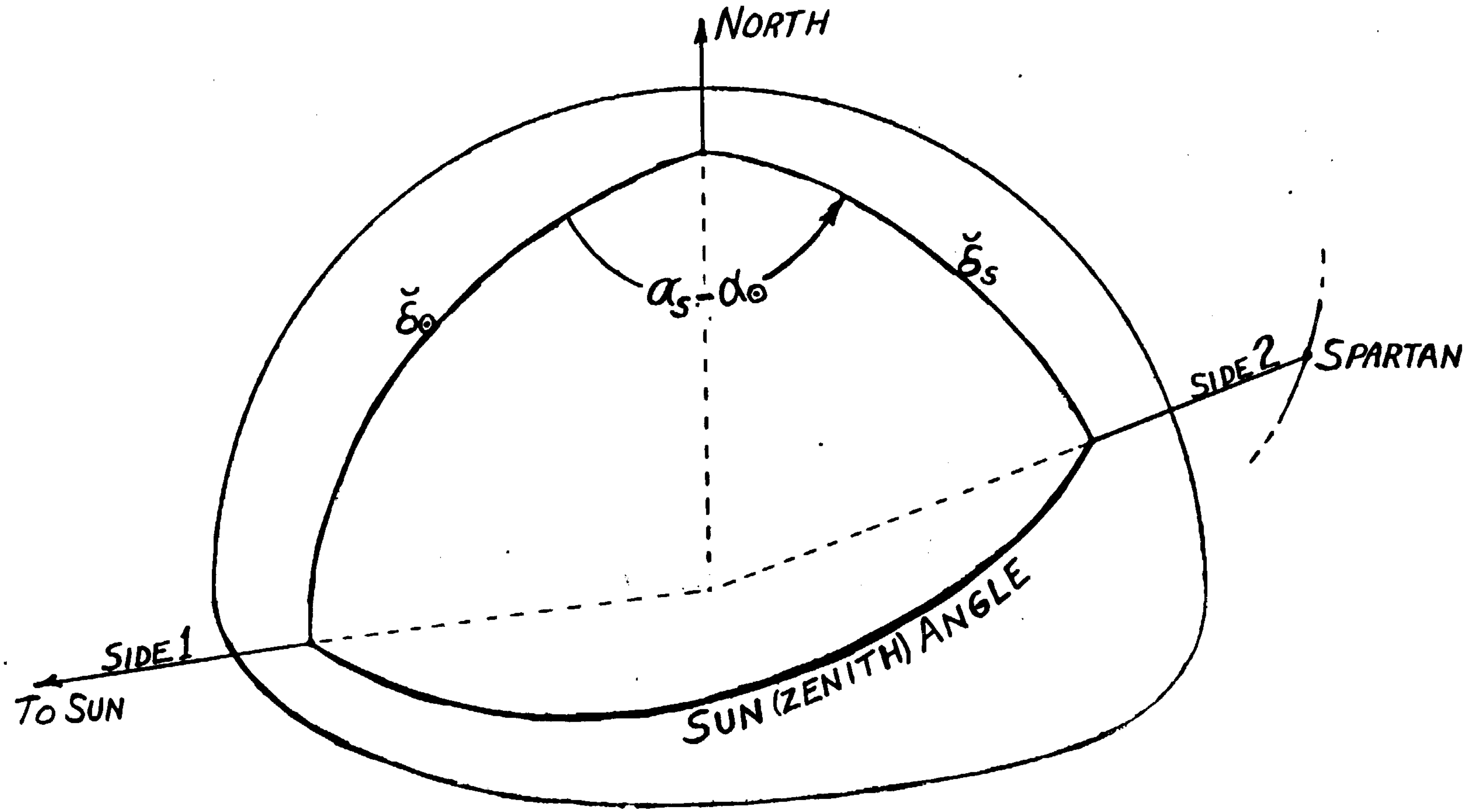
ILLUMINATION PRODUCED BY FLAT PLATE
(DIRECT SUNLIGHT ONLY)

- POSITION VECTOR OF SPARTAN, S
- VELOCITY VECTOR OF SPARTAN, V
- POINTING VECTOR OF SPARTAN, P (AND AZIMUTH OF ORTHOGONAL AXIS)
- SUN VECTOR (FROM EARTH), $\odot$
- ALBEDO ELEMENT VECTOR, e
- ELEMENT-TO-SPARTAN VECTOR, R

BASIC DIRECTIONS IN SPACE



V
R
e
E
G
N
O
EQUATOR



$$\text{SUN ANGLE} = \cos^{-1}[\cos\breve{\delta}_\odot \cos\breve{\delta}_S + \sin\breve{\delta}_\odot \sin\delta_S \cos(\alpha_S - \alpha_\odot)]$$

(SPHERICAL LAW OF COSINES)

GENERAL ANGLES FROM SIDES (SUN EXAMPLE) ⑧

ADVANTAGES:

- LONG-RANGE OPTICAL TRACKING FEASIBLE FOR SPARTAN (to several hundred km., under favorable conditions)
- FUNCTION IS ALL ON BOARD
- REQUIRED EQUIPMENT IS IN PLACE
- PASSIVE OPERATION
- LOW COST
- RELIABLE AND MAN-COMPATIBLE

(9)

NEEDS:

- MAXIMIZE DIFFUSE REFLECTANCE OF S/C EXTERIOR
- VERIFY OPERATION
- INCORPORATE INTO MISSION PLANS

2-98

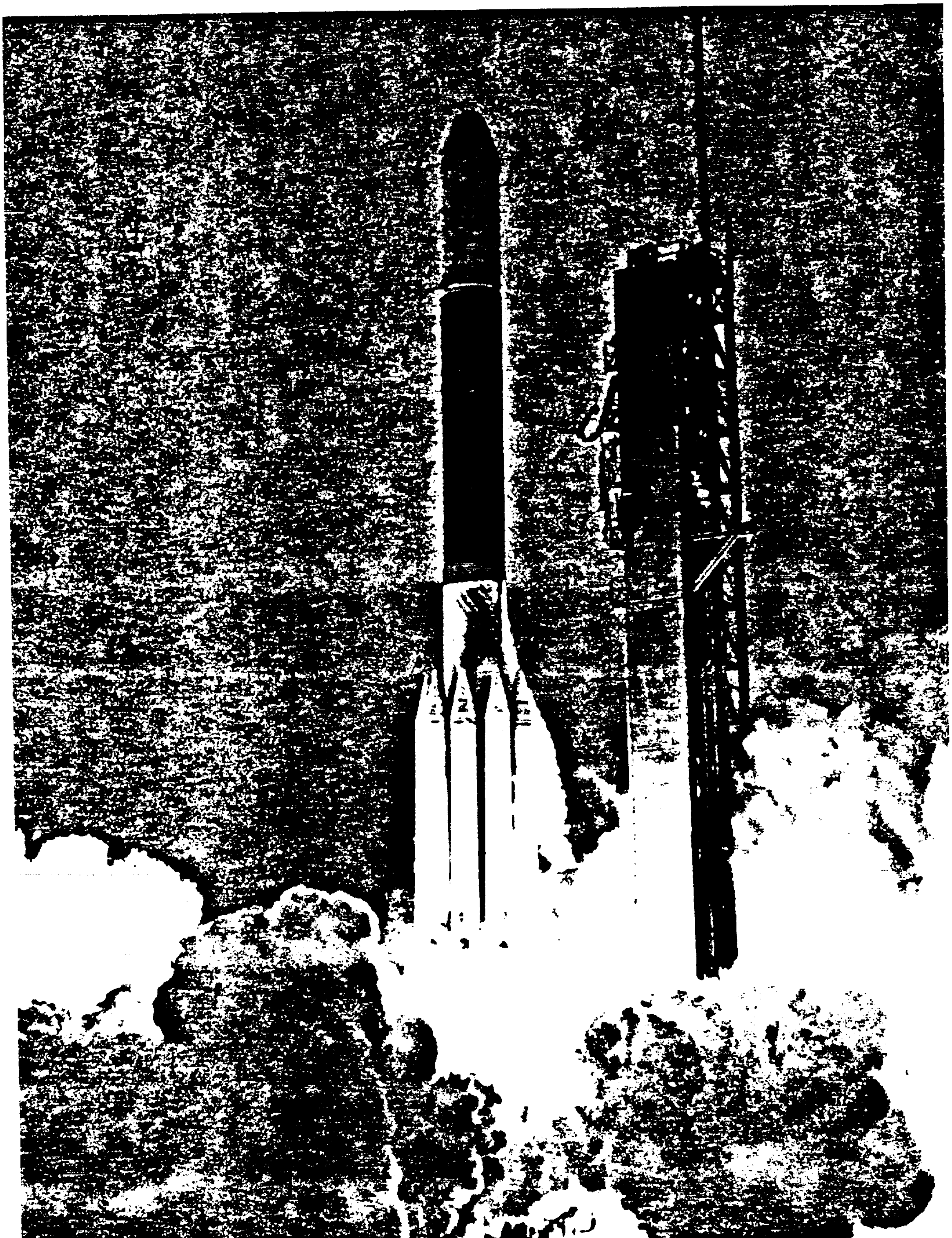
DYNAMICS OF SOLAR MAXIMUM MISSION SPACECRAFT CAPTURE AND REDEPLOYMENT ON STS 41-C

Kevin J. Grady
Goddard Space Flight Center

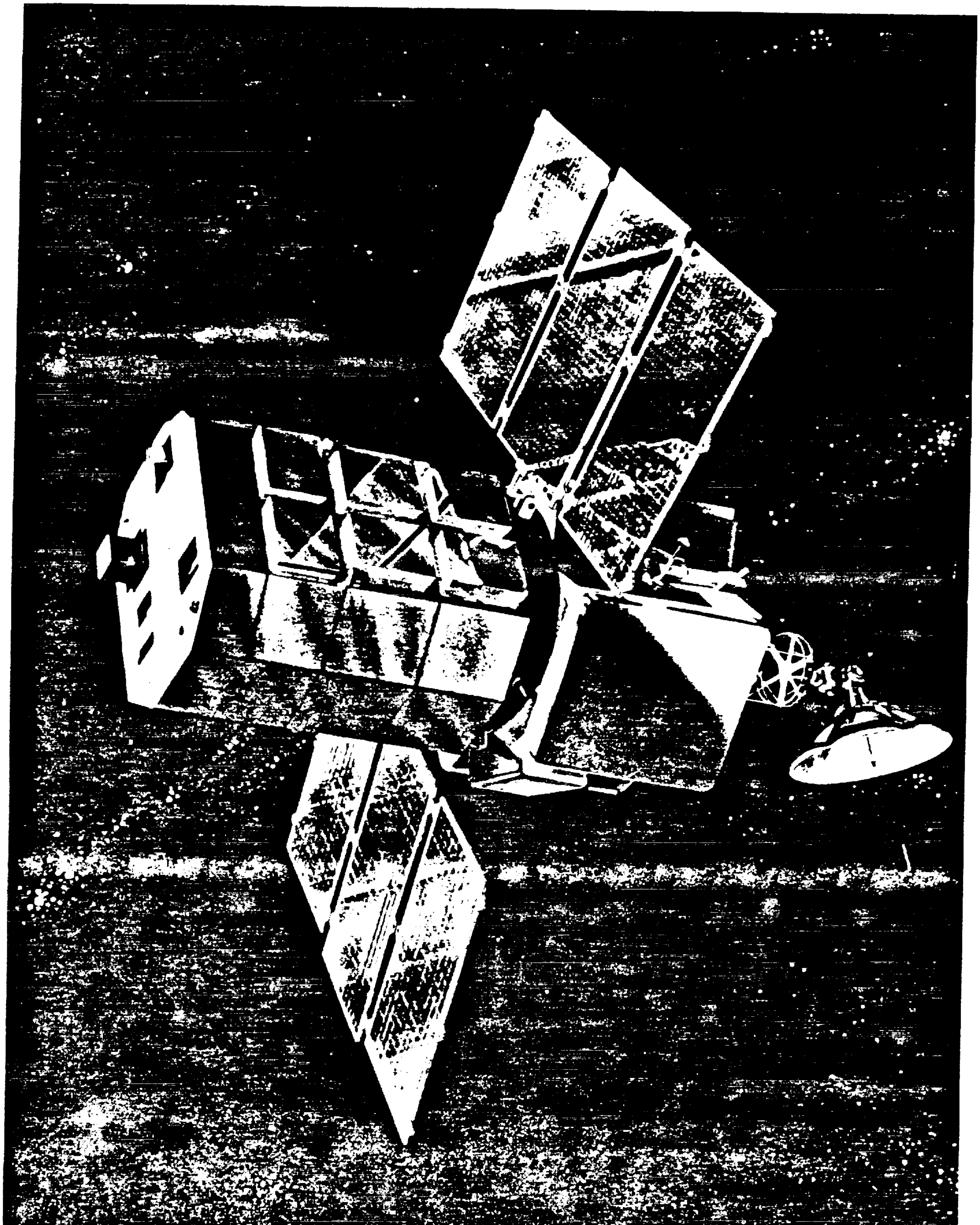
Rendezvous and Proximity Operations Workshop
Houston, Texas

February 19-22, 1985

GSFC



NASA-G-80-1121



SOLAR MAX HISTORY

LAUNCHED FEBRUARY 1980: NINE MONTHS FULLY OPERATIONAL

FAILURE IN ATTITUDE CONTROL ELECTRONICS, NOV/DEC 1980, RESULTED IN THE LOSS OF PRIMARY CONTROL ACTUATORS

SPIN-STABILIZED CONTROL (MAGNETIC TORQUERS)
- THREE INSTRUMENTS CONTINUE SCIENCE
- POTENTIAL FOR REPAIR

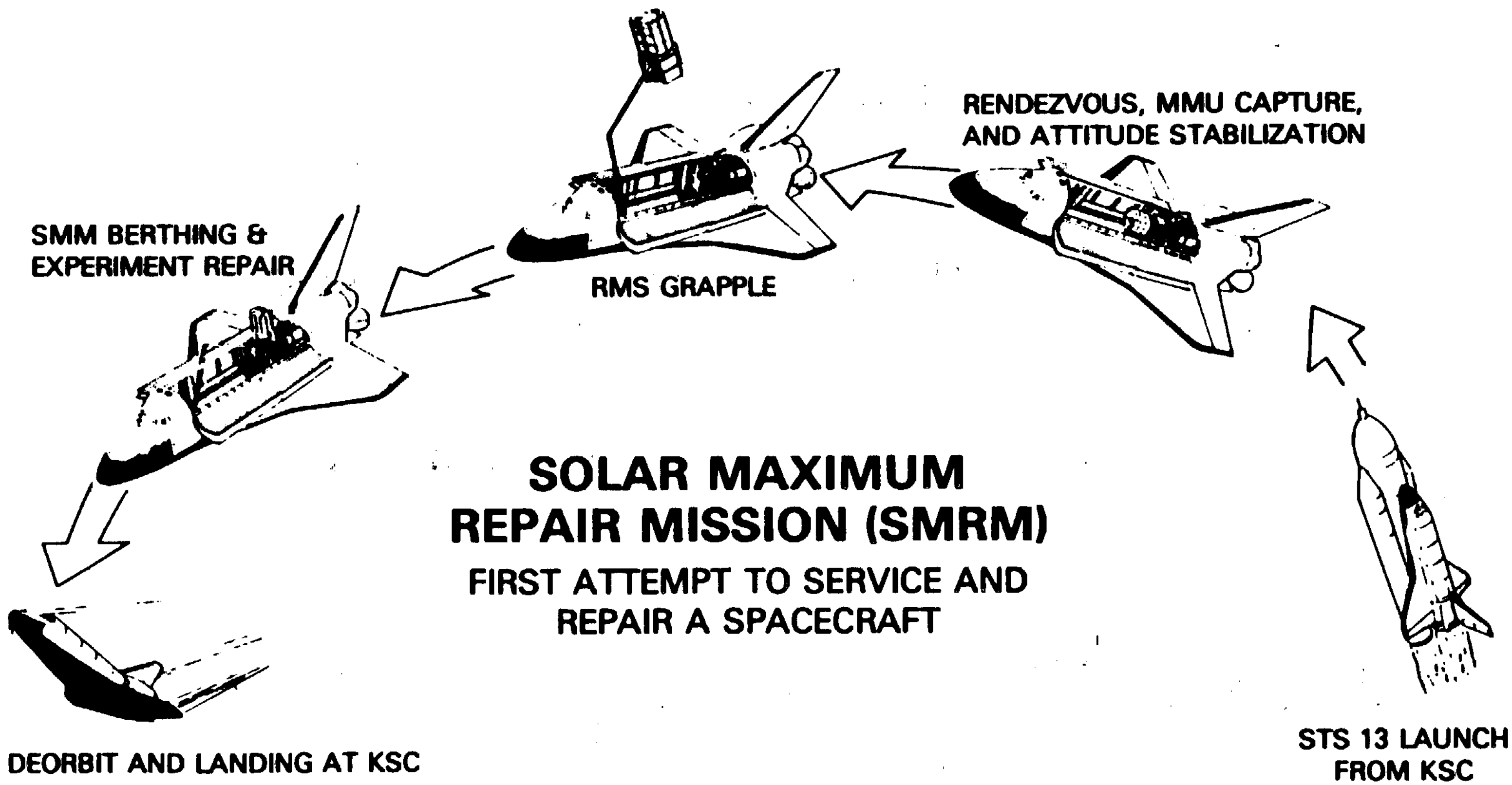
GSFC

SOLAR MAXIMUM REPAIR MISSION

REPAIR MISSION PLANNING INITIATED IN 1981

NOMINAL MISSION DESCRIPTION

GSFC



SOLAR MAXIMUM REPAIR MISSION (SMRM)

FIRST ATTEMPT TO SERVICE AND REPAIR A SPACECRAFT

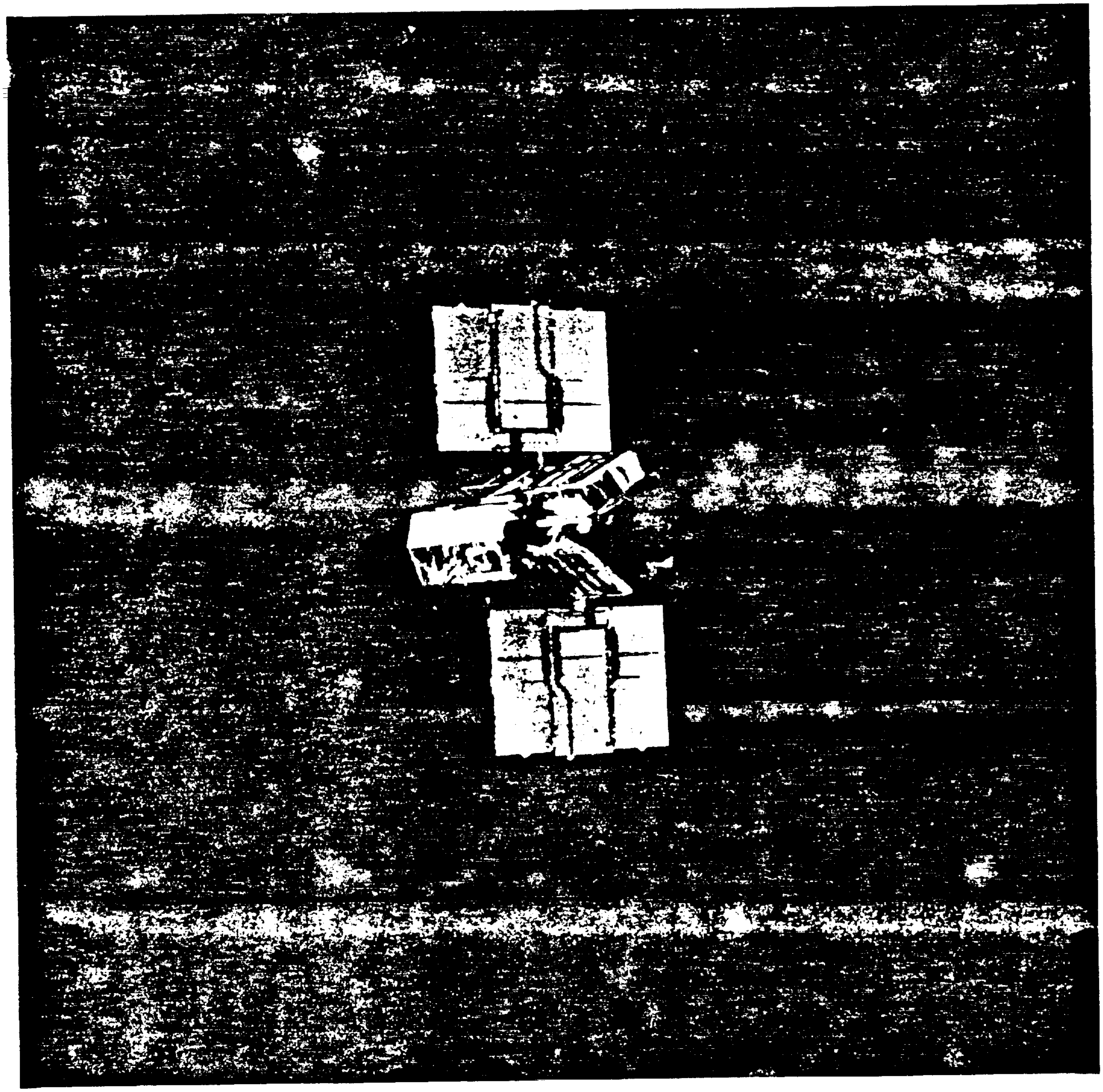
SOLAR MAX REPAIR MISSION (SMRM)

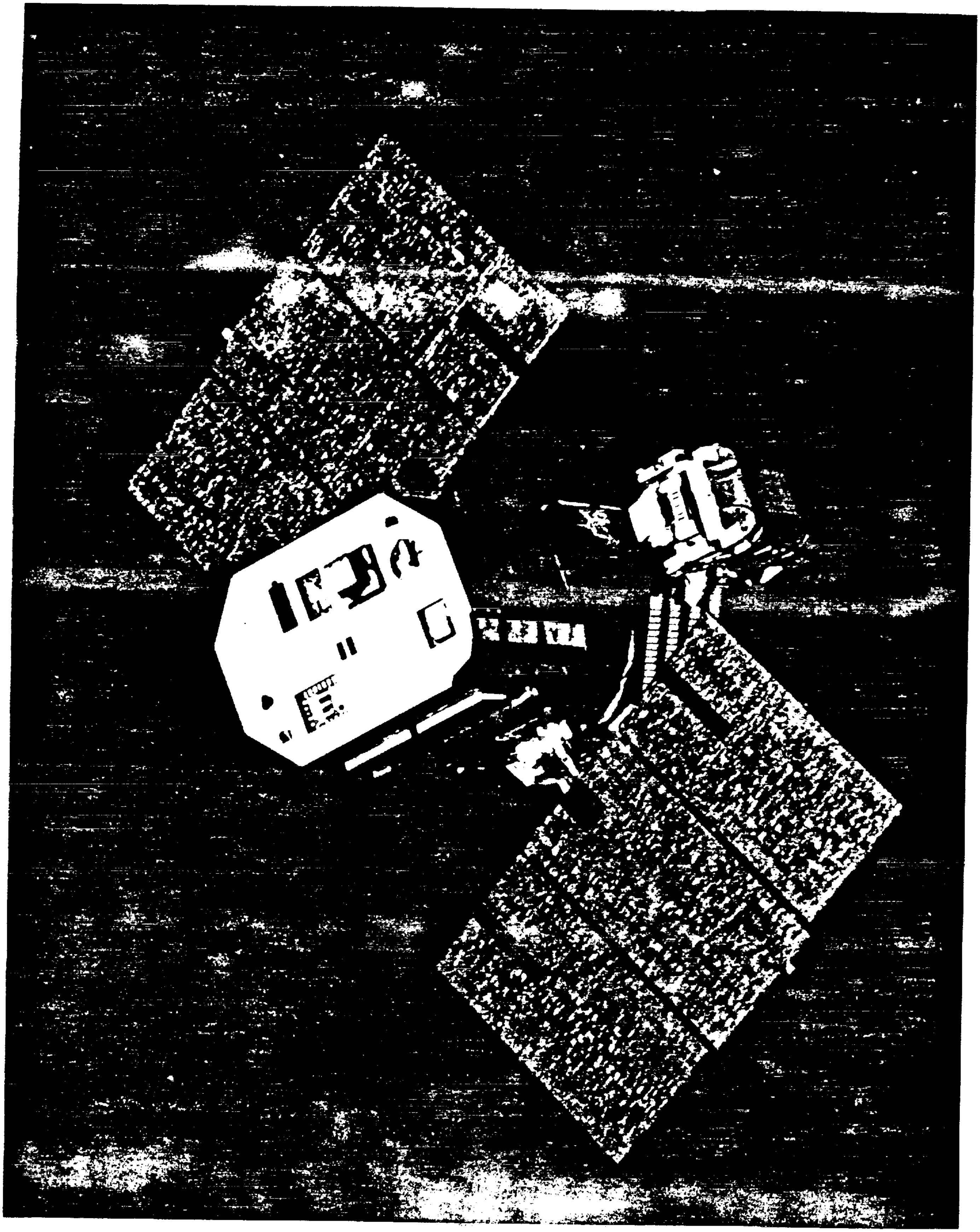
FUNDED IN 1982

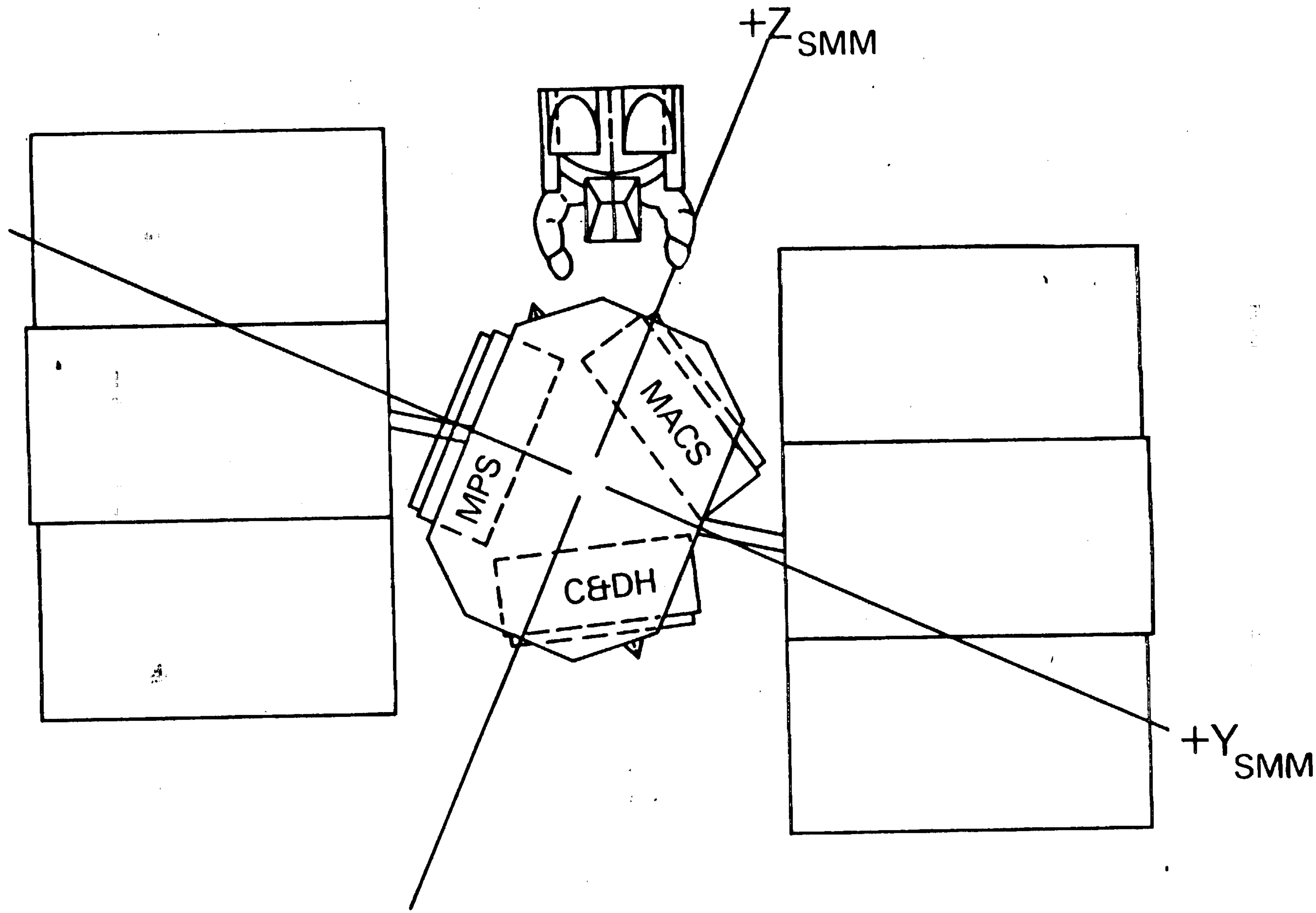
MANIFESTED ON STS 41-C

LAUNCHED APRIL 6, 1984

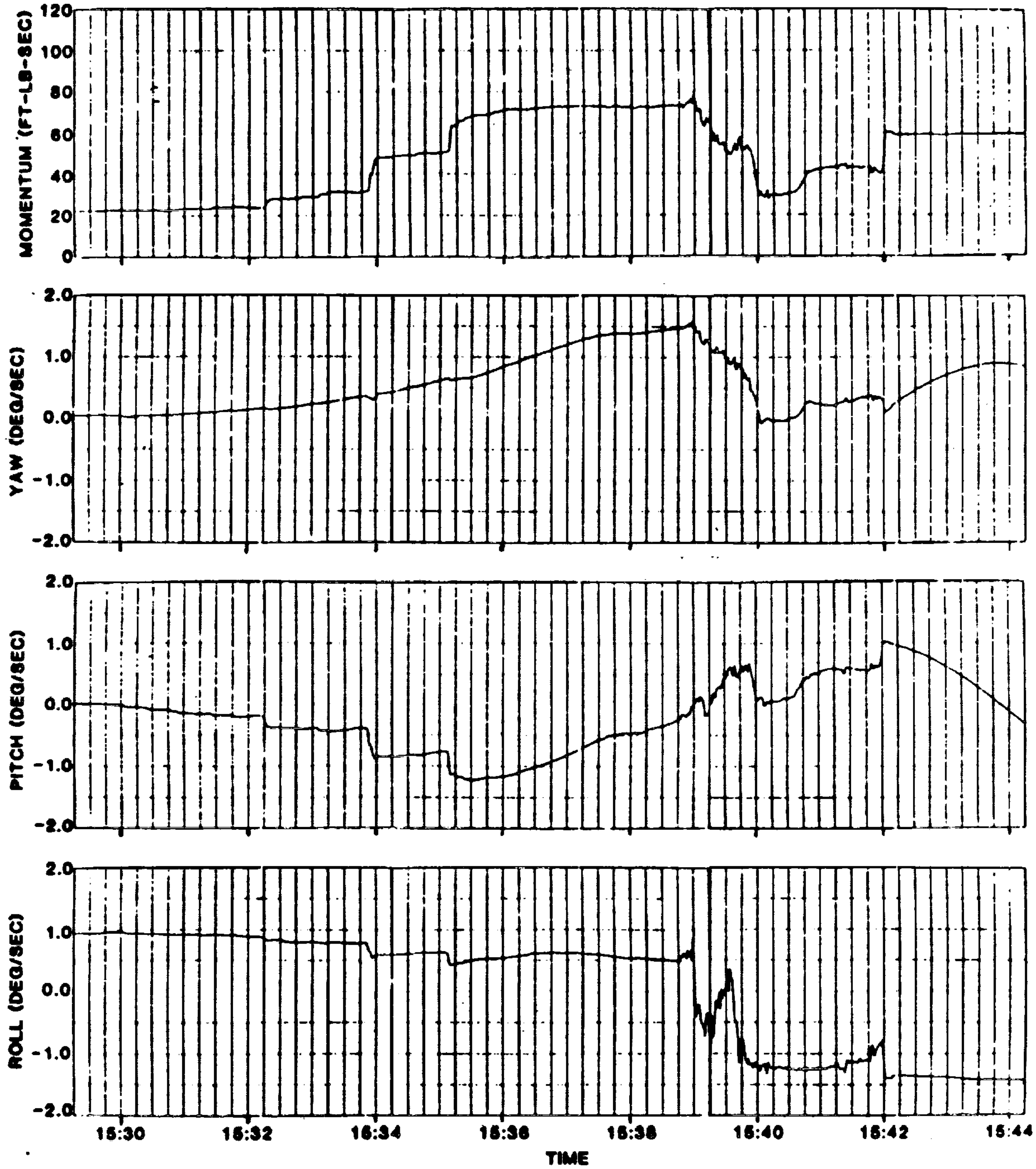
GSFC



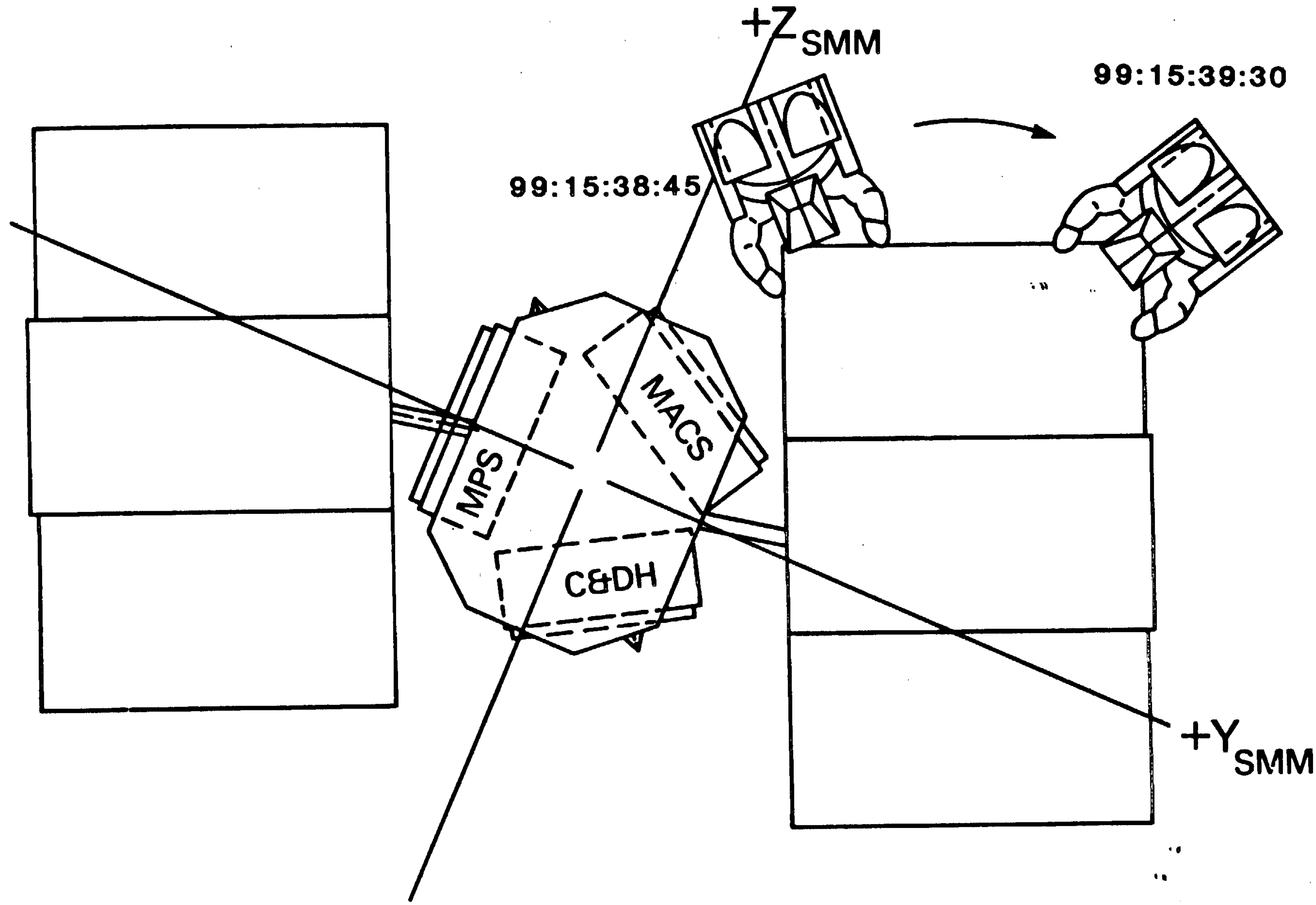




SMM DYNAMICS DURING PROXIMITY OPERATIONS



SMM DYNAMICS DURING PROXIMITY OPERATIONS



SMM DYNAMICS DURING PROXIMITY OPERATIONS

RECOVERY OF SOLAR MAX BY GSFC CONTROL CENTER

- MAGNETIC DESPIN CONTROL (-b dot) UTILIZED TO DESPIN SMM (80 ft-lb-sec)

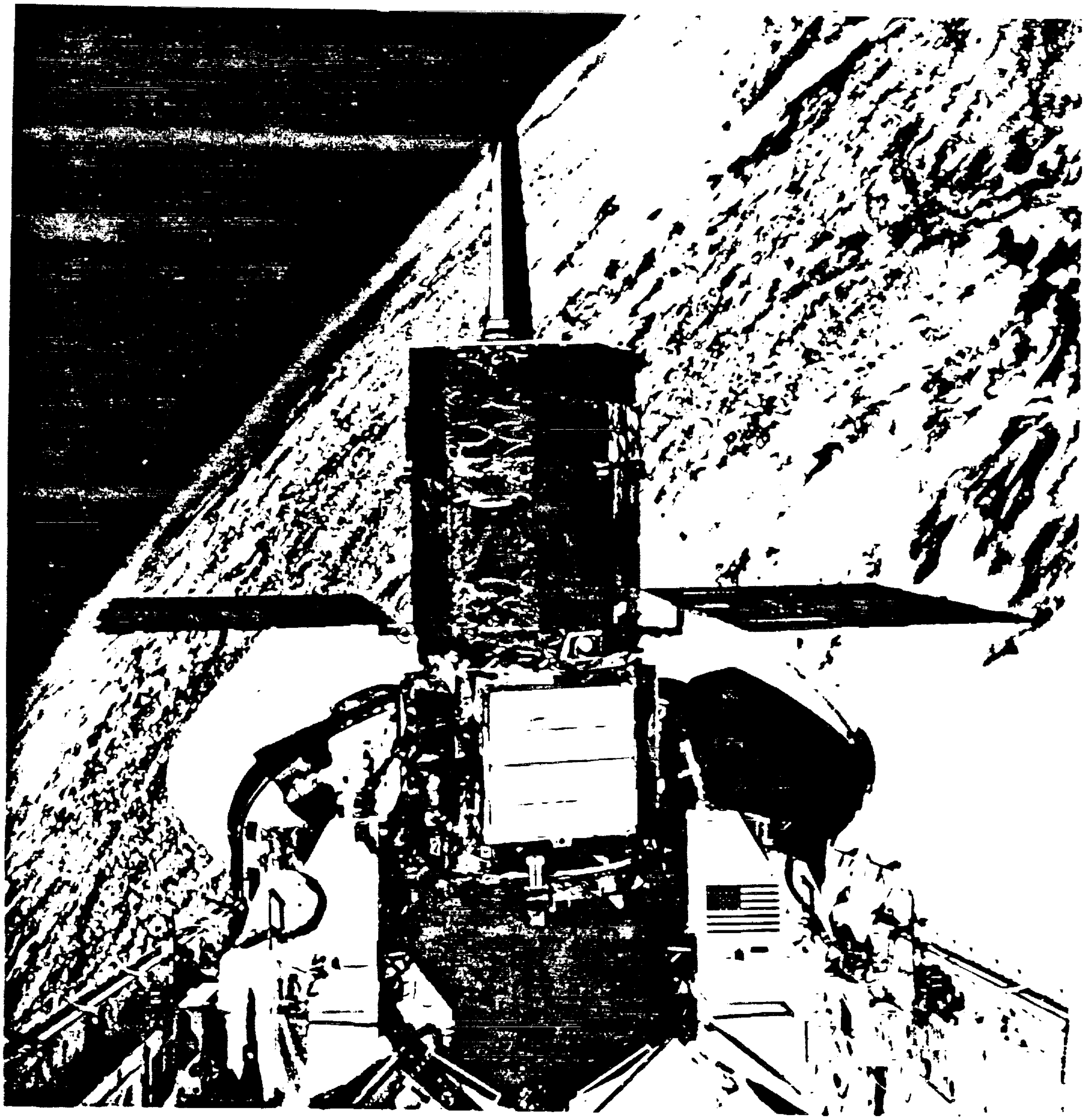
- MAGNETIC SPIN-STABILIZED CONTROLLER UTILIZED TO REESTABLISH STABLE SUN POINTING ATTITUDE

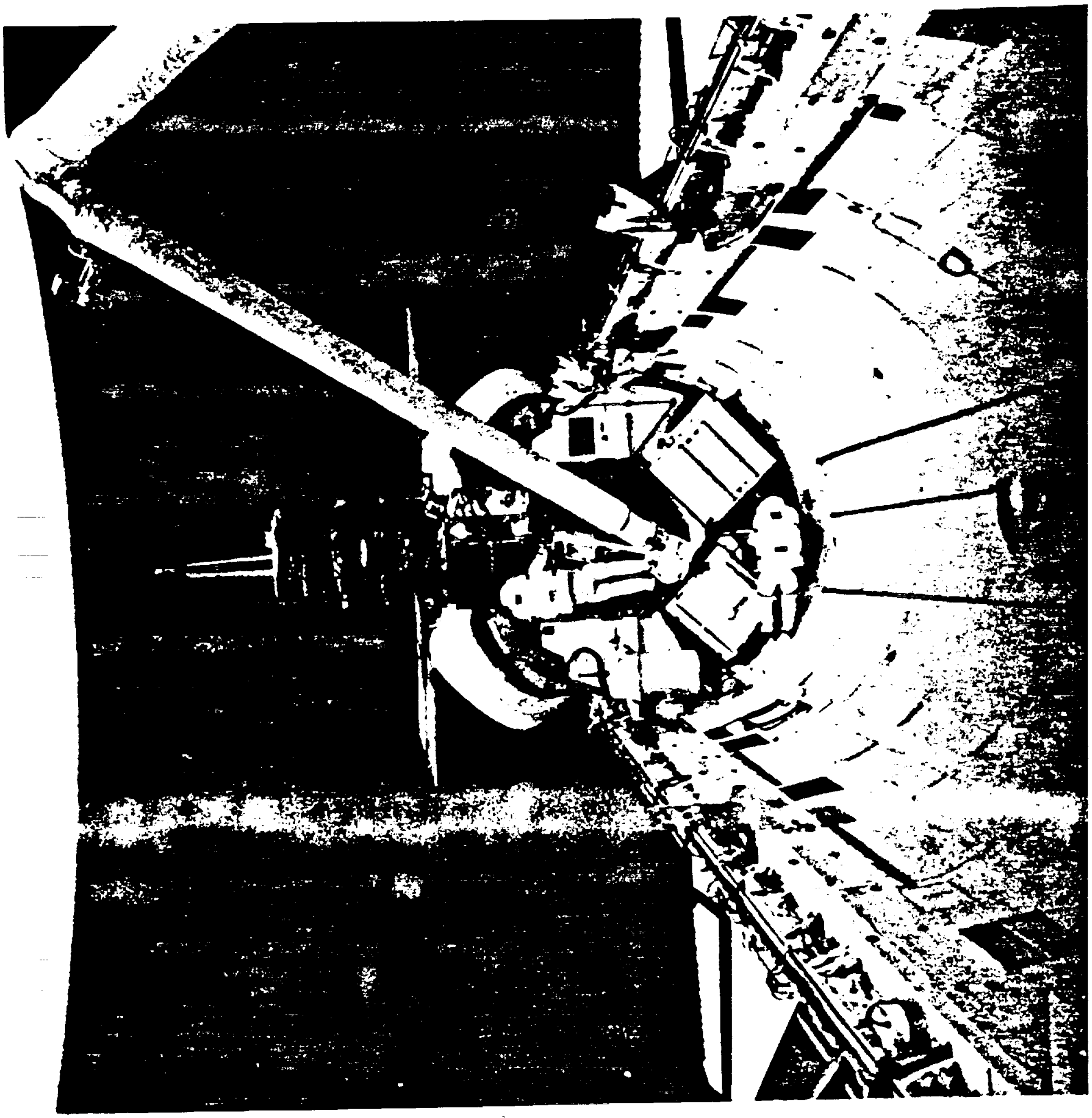
RMS GRAPPLE OF SOLAR MAX

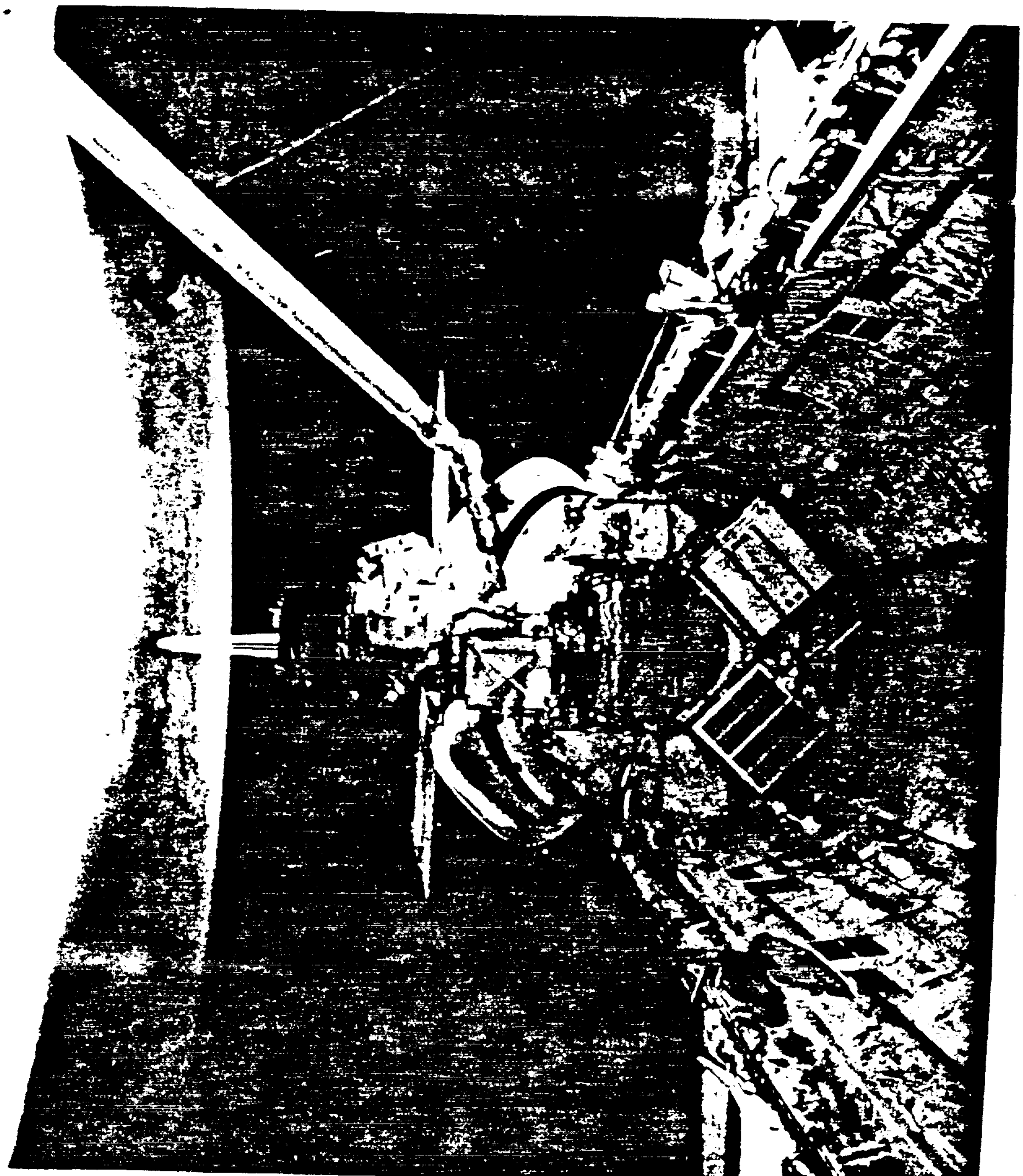
SPACECRAFT ROLLING AT 0.5 DEG/SEC

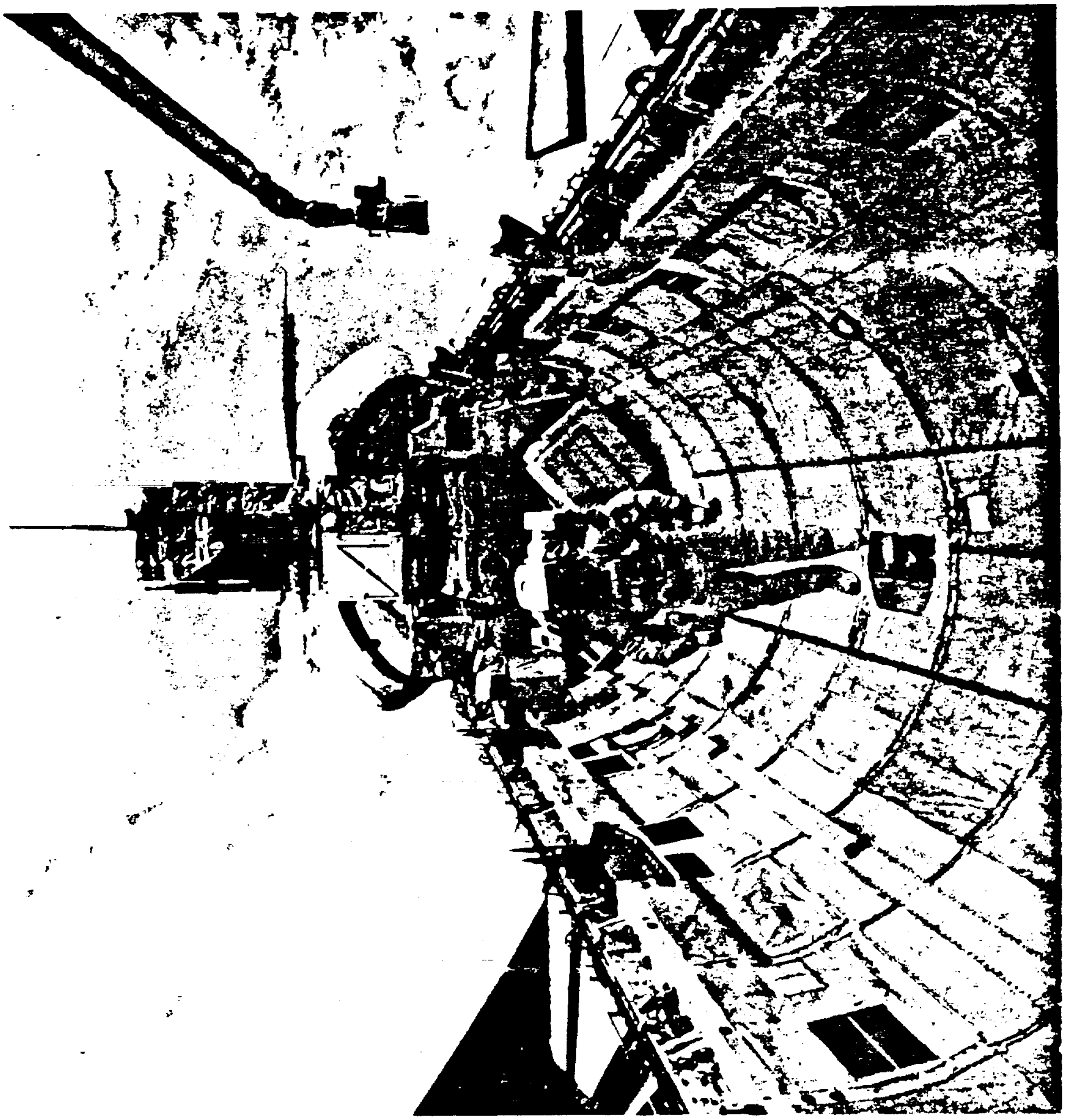
RMS GRAPPLE SUCCESSFUL ON APRIL 10, 1984

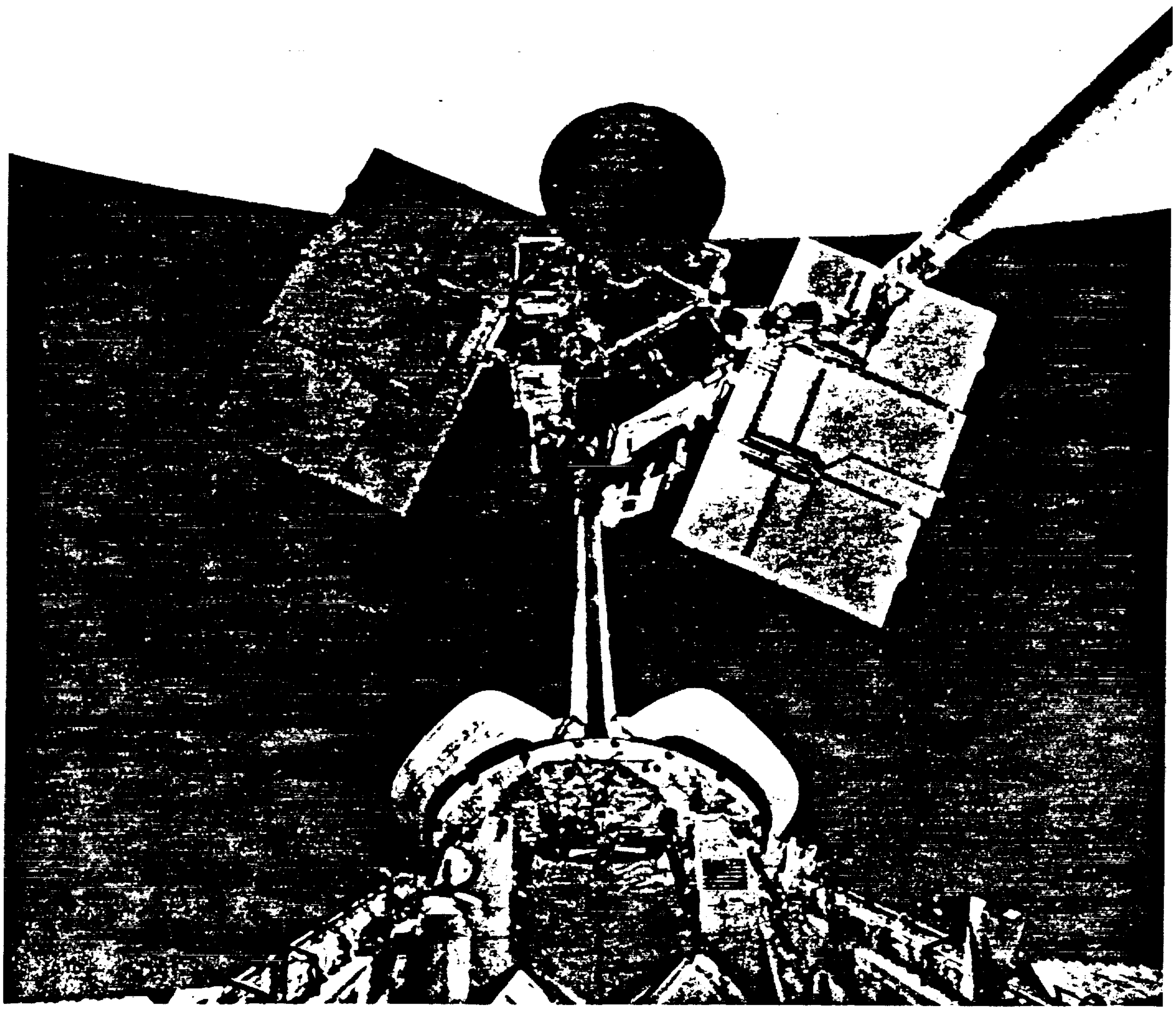
GSFC

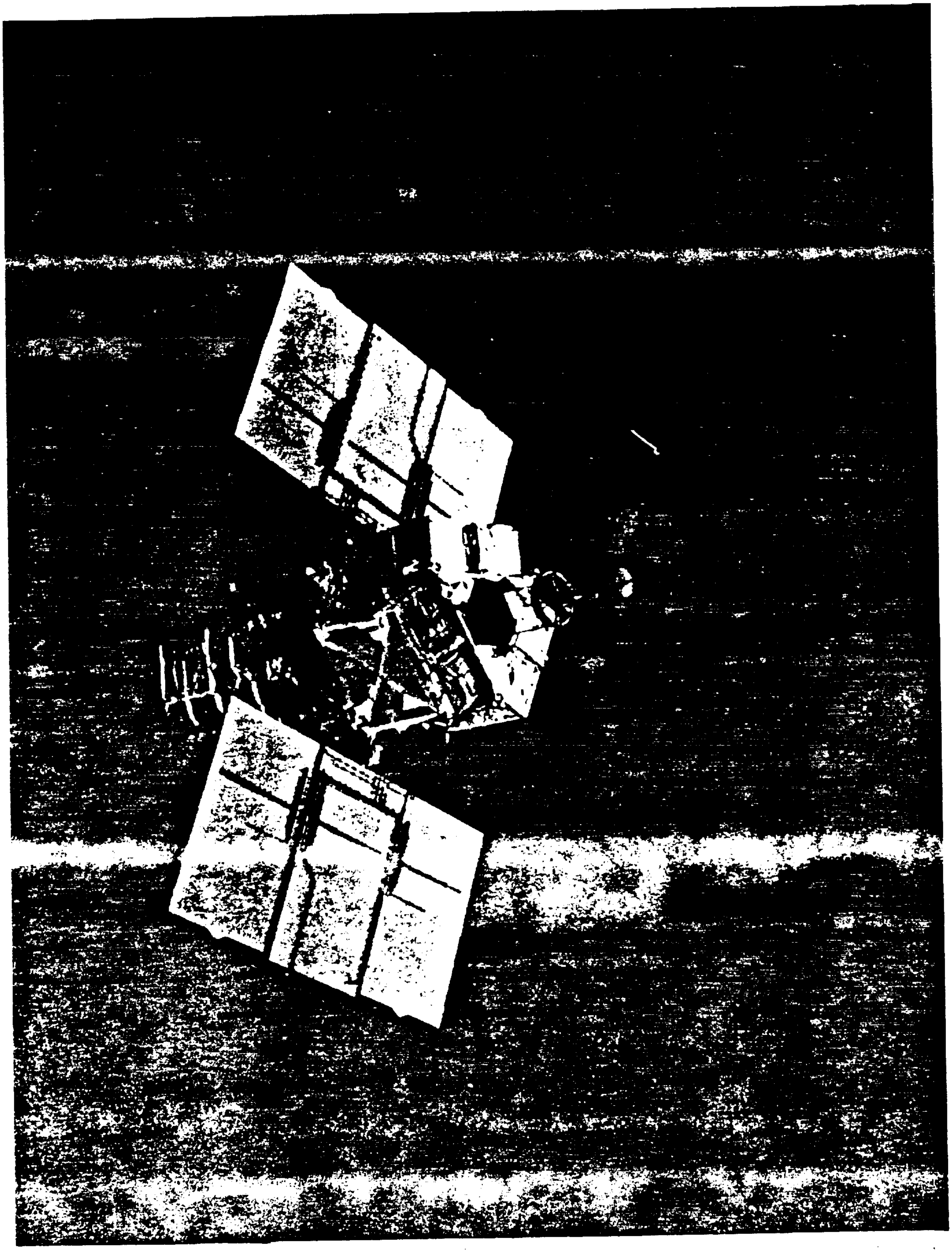












RMS RELEASE OF SOLAR MAX

RELEASE RATES:

- ROLL – 0.074 DEG/SEC
- PITCH – 0.012 DEG/SEC
- YAW – 0.018 DEG/SEC

ORBITER INFLUENCE ON SUN SENSORS

CONCLUSIONS: LESSONS LEARNED

LARGE DISTURBANCE TORQUE CONTINGENCIES

ORBITER EFFECTS ON OPTICAL SENSORS

NON-IMPACT GRAPPLE FIXTURES

MMU AND SATELLITE PROXIMITY OPERATIONS

CONCLUSIONS: LESSONS LEARNED

OPTICAL INSTRUMENT PROTECTIVE COVERS

SATELLITE CHECKOUT IN ORBITER

MODULAR/REPAIRABLE SPACECRAFT (ORU CONCEPT)

LEASECRAFT/MATERIALS PROCESSSING

RENDEZVOUS, PROXIMITY OPERATIONS

AND

COST TRADEOFFS

DR. R. E. O'BRIEN
FAIRCHILD SPACE COMPANY

RENDEZVOUS & PROXIMITY
OPERATIONS WORKSHOP
FEBRUARY 19-22, 1985
LYNDON B. JOHNSON SPACE
CENTER

INTRODUCTION

LEASECRAFT IS A LOW EARTH-ORBITING PLATFORM WHICH PROVIDES LEASED SERVICES FOR NASA AND COMMERCIAL USERS. FOR ITS SPACE MANUFACTURING CUSTOMERS LEASECRAFT MUST PROVIDE PERIODIC PRODUCT RETRIEVAL AND FACTORY REFURBISHMENT OR RESUPPLY. THE PLATFORM CONFIGURATION AND MISSION OPERATIONS HAVE BEEN DESIGNED TO MAINTAIN THE FLEXIBILITY OF FLYING LOW-G MISSIONS ALONG WITH ASTROPHYICS MISSIONS WHILE MAINTAINING COST EFFECTIVENESS. THIS PRESENTATION DESCRIBES THE CURRENT BASELINE LEASECRAFT RENDEZVOUS AND PROXIMITY OPERATIONS DESIGN FOR THE MATERIALS PROCESSING PLATFORM AND DETAILS SEVERAL OF THE COST TRADES WHICH DRIVE THIS DESIGN.

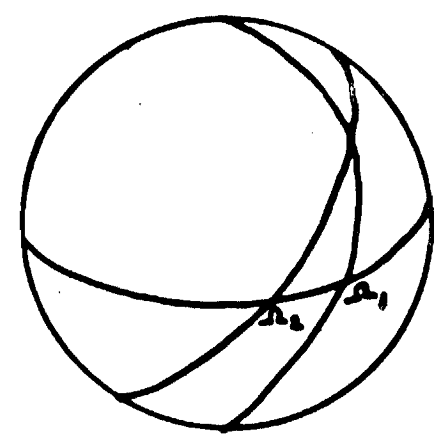
RENDEZVOUS OPERATIONS

- MATERIALS PROCESSING MISSIONS NEED DEPENDABLE, REGULARLY SCHEDULED SERVICE TO GET PRODUCT INTO MARKET PLACE IN A TIMELY, RELIABLE MANNER
- PHASE REPEATING ORBIT PROVIDES MAXIMUM NUMBER OF LAUNCH OPPORTUNITIES
- CO-MANIFESTED PAYLOADS SHOULD HAVE NODAL REQUIREMENTS COMPATIBLE WITH PHASE REPEATING ORBIT NODE AND NODAL REGRESSION RATE
- PROBLEM: COMM SATS MANIFESTED ON MATERIALS FLIGHTS NOT EASILY REMANIFESTED

FAIRCHILD SPACE COMPANY

WHAT'S IN A RENDEZVOUS?

- ALTITUDE
- INCLINATION
- PHASE
- NODAL CROSSING

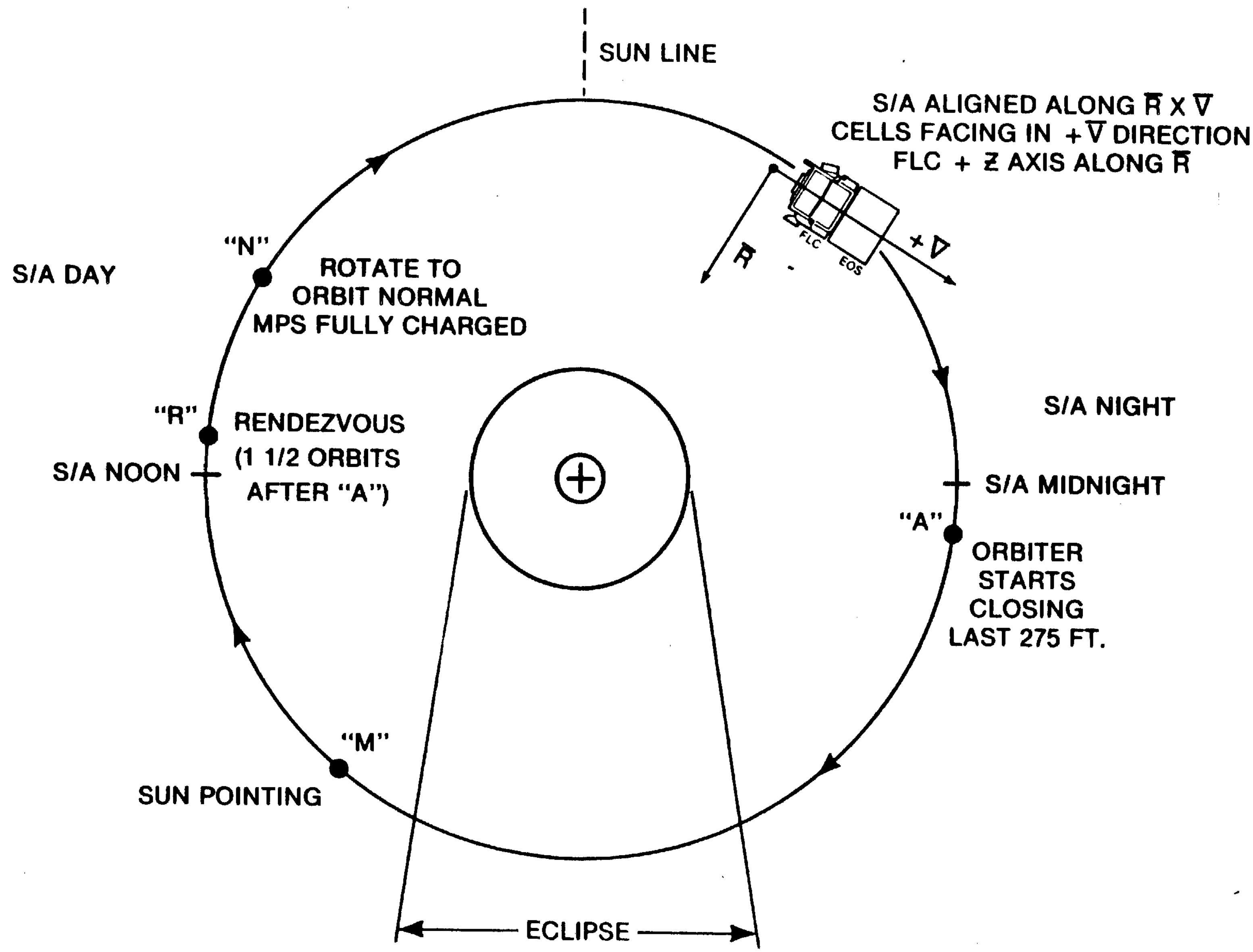


FAIRCHILD
SPACE COMPANY

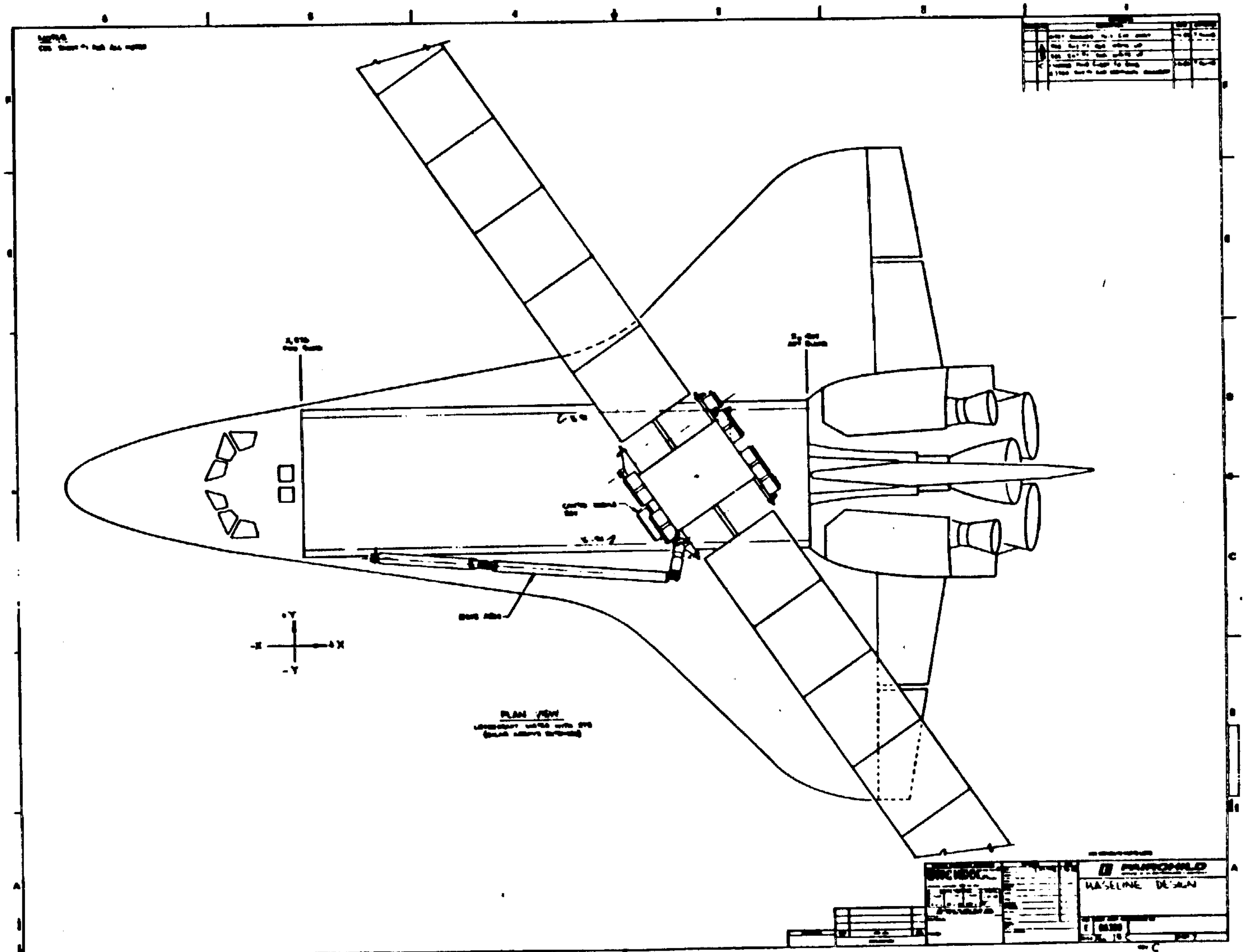
PROXIMITY OPERATIONS

- MATERIAL PROCESSING MISSIONS REQUIRE PERIODIC (6 MONTH INTERVALS) PAYLOAD SERVICING/EXCHANGE. THIS SHOULD BE A NOMINAL MISSION USING A NASA STANDARD RENDEZVOUS AND SERVICING TIMELINE (1 DAY) TO MINIMIZE COST AND SHUTTLE PLANNING
- MATERIALS PROCESSING REQUIRES SUBSTANTIAL POWER THROUGH RETRIEVAL TO CONTROL TEMPERATURE -- EOS - 1 KW -- CRYSTAL GROWTH FURNACES UNKNOWN
- POWER REQUIREMENTS DRIVE S/C ORIENTATION AND RETRIEVAL TIMELINE.
- SOLAR ARRAY AND APPENDAGE RETRACTION
  - INCREASED BATTERY SIZE OR DOD VERSUS OPERATIONAL PROBLEMS (PLUME IMPINGEMENT) AND THERMAL CONCERN
  - RETRACTING ARRAYS REQUIRES S/C HARDWARE TO STS POWER WITH ATTENDANT DELAY

LEASECRAFT PROXIMITY OPERATION



LEASECRAFT MATED WITH STS
(SOLAR ARRAYS EXTENDED)



FAIRCHILD SPACE COMPANY

COST TRADEOFFS

- SERVICE ALTITUDE
  - COST TO REFUEL AND INCREASE SPACECRAFT PERFORMANCE, AND THE SCHEDULE RISK OF OPERATIONS IN LOWER ORBIT VERSUS INCREASED TRANSPORTATION COST, DECREASED SPACECRAFT COST AND SCHEDULE RISK OF $260.3 NMI OPERATIONS
- APPENDAGE RETRACTION AND SERVICE DESIGN
  - IF IT WORKS DON'T TURN IT OFF
  - SWITCH TO TURN OFF P/L INTRODUCES FAILURE MODE
  - MINIMIZE TIMELINE IN ORBITER CARGO BAY -- NO INCURRED COST FOR EXTRA DAYS ON-ORBIT

LMSC/F020766
19 FEBRUARY 1985

SPACE TELESCOPE

PRESENTED BY

THOMAS E. STYCZYNSKI, STAFF ENGINEER
LOCKHEED MISSILES AND SPACE COMPANY

NASA RENDEZVOUS AND PROXIMITY OPERATIONS WORKSHOP
19-22 FEBRUARY 1985

LOCKHEED MISSILES & SPACE COMPANY, INC.
SPACE SYSTEMS DIVISION · SUNNYVALE, CALIFORNIA

FOREWORD

THIS DOCUMENT WAS PREPARED FOR PRESENTATION AT THE NASA RENDEZVOUS AND PROXIMITY OPERATIONS WORKSHOP. NASA JOHNSON SPACE CENTER 19-22 FEBRUARY 1985.

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CONTENTS

ABBREVIATIONS

ATP	Authorization to Proceed
AXAF	Advanced X-Ray Astronomical Facility
ESA	European Space Agency
EVA	Extra - Vehicular Activity
FSS	Flight Support System
GHz	Gigahertz
GSFC	Goddard Space Flight Center
Hr	Hour
JPL	Jet Propulsion Labs
JSC	Johnson Space Center
KHz	Kilohertz
M	Meter
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Adminsitration
NM	Nautical Miles
OMM	Orbital Maintenance Mission
OMS	Orbital Maneuvering System
OMV	Orbital Maneuvering Vehicle
ORU	Orbital Replaceable Unit
OTA	Optical Telescope Assembly
PRCS	Primary Reaction Control System
RF	Radiofrequency
RMS	Remote Manipulator System
SI	Scientific Instrument
SIRTF	Space Infrared Telescope Facility
SSE	Space Support Equipment
SSM	Support Systems Module
ST	Space Telescope
STA	Station
STOCC	Space Telescope Operations Control Center
STS	Space Transportation System
TDRSS	Tracking Data Relay Satellite System
V	Volt
VDC	Volts Direct Current
WHR	Watt Hours

- SPACE TELESCOPE OVERVIEW

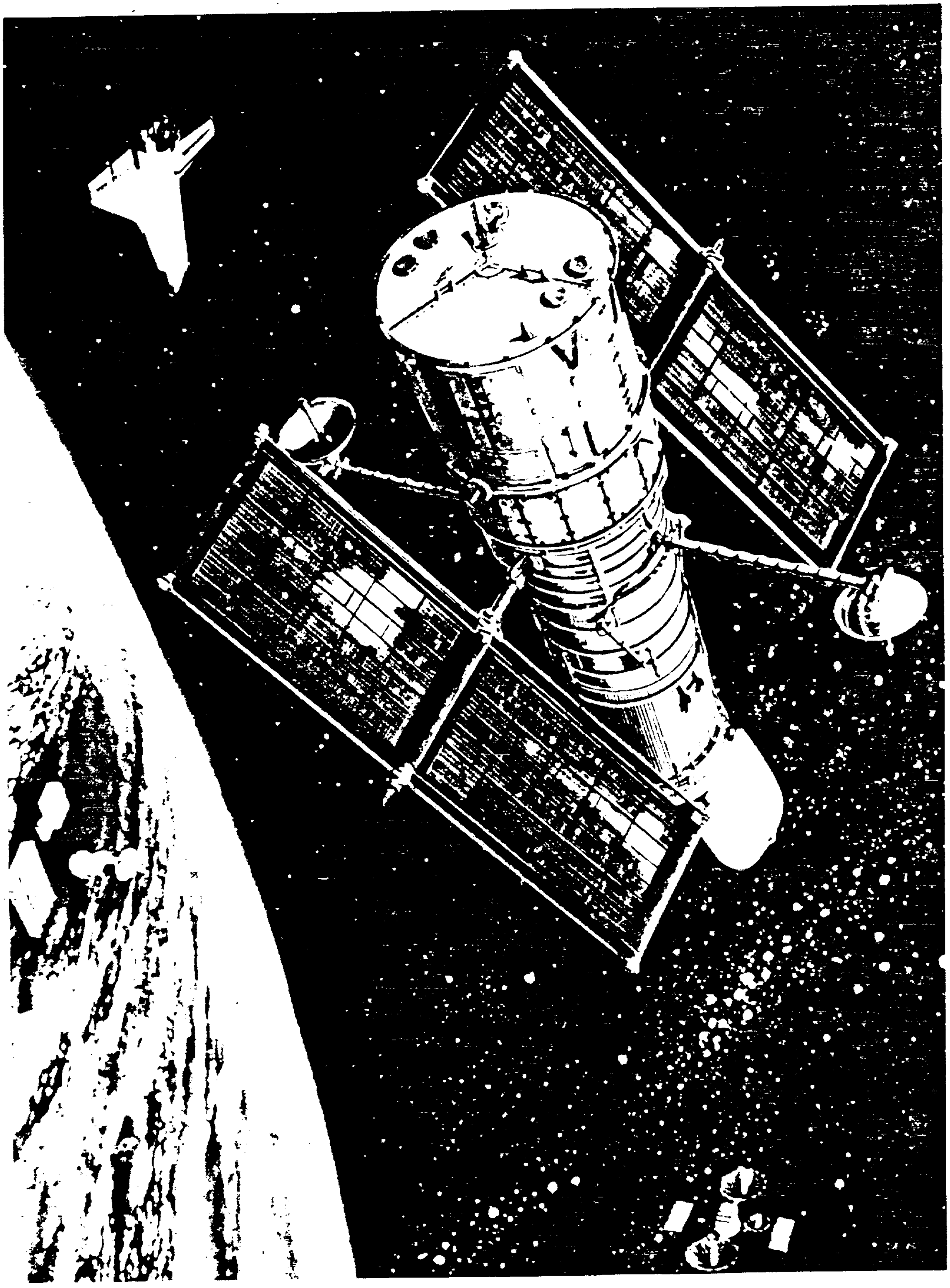
ST PROGRAM OVERVIEW

THE SPACE TELESCOPE (ST) IS AN UNMANNED ORBITING OBSERVATORY DESIGNED FOR A 15-YEAR LIFESPAN UTILIZING ORBITAL MAINTENANCE MISSIONS TO IMPROVE SYSTEM EFFICIENCY AND RE-BOOST MISSION TO COMPENSATE FOR ORBITAL DECAY. AT ANY TIME DURING THE ORBITAL LIFE THE ST MAY RETURN TO EARTH FOR A LIMITED OR COMPLETE GROUND REFURBISHMENT.

THE ST IS APPROXIMATELY 43 FEET IN LENGTH AND 14 FEET IN DIAMETER AT THE AFT SHROUD. THE FORWARD SHELL OF THE ST IS 10 FEET IN DIAMETER TO PROVIDE ROOM FOR FOLDED APPENDAGES, SOLAR ARRAYS AND HIGH GAIN ANTENNAS, ALLOWING ST TO FIT INTO THE SHUTTLE CARGO BAY ENVELOPE.

THE CURRENT REQUIREMENTS CALL FOR A 320NM ORBIT AT A 28.5 DEGREE INCLINATION. HOWEVER, DUE TO POSSIBLE OPERATIONAL CONSTRAINTS DURING AN EARLY PEAK SOLAR ACTIVITY CYCLE THIS ORBIT MAY BE INCREASED.

THE ST IS DIVIDED INTO TWO MAJOR SUBSYSTEMS. THE OPTICAL TELESCOPE ASSEMBLY (OTA) STRUCTURE IS LOCATED INSIDE THE ST AND SUPPORTS FIVE SCIENTIFIC INSTRUMENTS, PRIMARY AND SECONDARY MIRRORS AND THE POINTING CONTROL SENSING SYSTEMS. THE SUPPORT SYSTEM MODULE (SSM) PORTION OF THE ST SURROUND THE OTA STRUCTURE PROVIDNG PROTECTION AND ACTS AS THE PRIMARY SUPPORT FOR ALL OTHER SUBSYSTEMS AS WELL AS SPACE TRANSPORTATION SYSTEM (STS) AND MAINTENANCE MISSION INTERFACES. THE ST UTILIZES REACTION WHEELS AND MAGNETIC TORQUERS FOR POINTING CONTROL STABILITY.



SPACE TELESCOPE SYSTEM

THE ST SATELLITE IS ONE ELEMENT OF THE SPACE TELESCOPE PROGRAM.

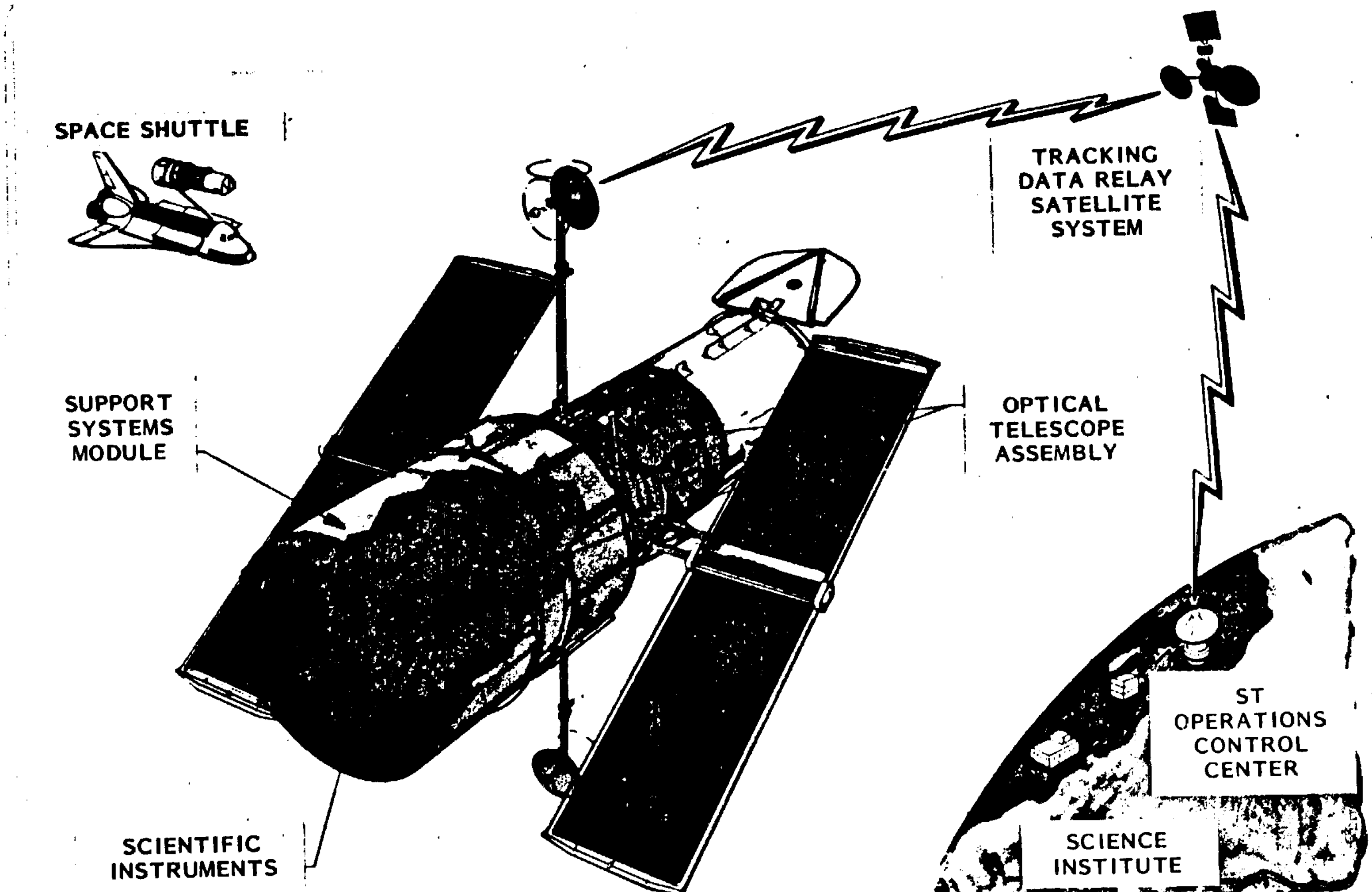
THE SPACE SHUTTLE PLAYS AN IMPORTANT ROLE ACTING AS LAUNCH VEHICLE, A MAINTENANCE PLATFORM, A REBOOST VEHICLE TO EXTEND THE ST ORBITAL LIFE AND PROVIDING THE MEANS OF EARTH RETURN.

ST DATA ACCUMULATION AND IN ORBIT CONTROL IS PROVIDED BY THE ST OPERATIONS CONTROL CENTER (STOCC) LOCATED AT GODDARD SPACE FLIGHT CENTER (GSFC). ALL COMMUNICATION WILL BE VIA THE TRACKING DATA RELAY SATELLITE SYSTEM (TDRSS).

THE ST SCIENCE INSTITUTE LOCATED AT JOHN HOPKINS UNIVERSITY WILL BE RESPONSIBLE FOR THE ACCUMULATION AND DISSIMINATION OF SCIENCE DATA AND DETERMINATION OF VIEWING PRIORITIES.

THE SCIENTIFIC INSTRUMENTS (SI'S) CAME FROM A VARIETY OF SOURCES INCLUDING THE EUROPEAN SPACE AGENCY (ESA), UNIVERSITY OF WISCONSIN, JET PROPULSION LABS (JPL) AND UNIVERSITY OF CALIFORNIA, SAN DIEGO/MARTIN MARIETTA. GSFC AND THE ST SCIENCE INSTITUTE HAVE RECENTLY ANNOUNCED THE OPPORTUNITY TO DEVELOP THE NEXT GENERATION OF SCIENTIFIC INSTRUMENTS FOR REPLACEMENT IN ORBIT.

SPACE TELESCOPE SYSTEM



o ST/STS MISSION INTERFACE

ST/STS MISSION OVERVIEW

ST IS DESIGNED TO UTILIZE THE SPACE TRANSPORTATION SYSTEM (STS) IN THE FOLLOWING SPECIFIC MISSIONS:

- o DEPLOYMENT
- o UNSCHEDULED MAINTENANCE IN THE EVENT OF APPENDAGE DEPLOYMENT OR UMBILICAL DISCONNECT FAILURES
- o IN ORBIT MAINTENANCE ON SCHEDULED 2-5 YEAR INTERVALS OR ON SHARED MISSION BETWEEN INTERVALS
- o REBOOST TO COMPENSATE FOR ORBITAL DECAY
- o EARTH RETURN

THESE MISSIONS AND RELATED HARDWARE ELEMENTS WILL BE DESCRIBED IN GREATER DETAIL.

ST/STS MISSION OVERVIEW

LMSC/F020766
19 FEBRUARY 1985

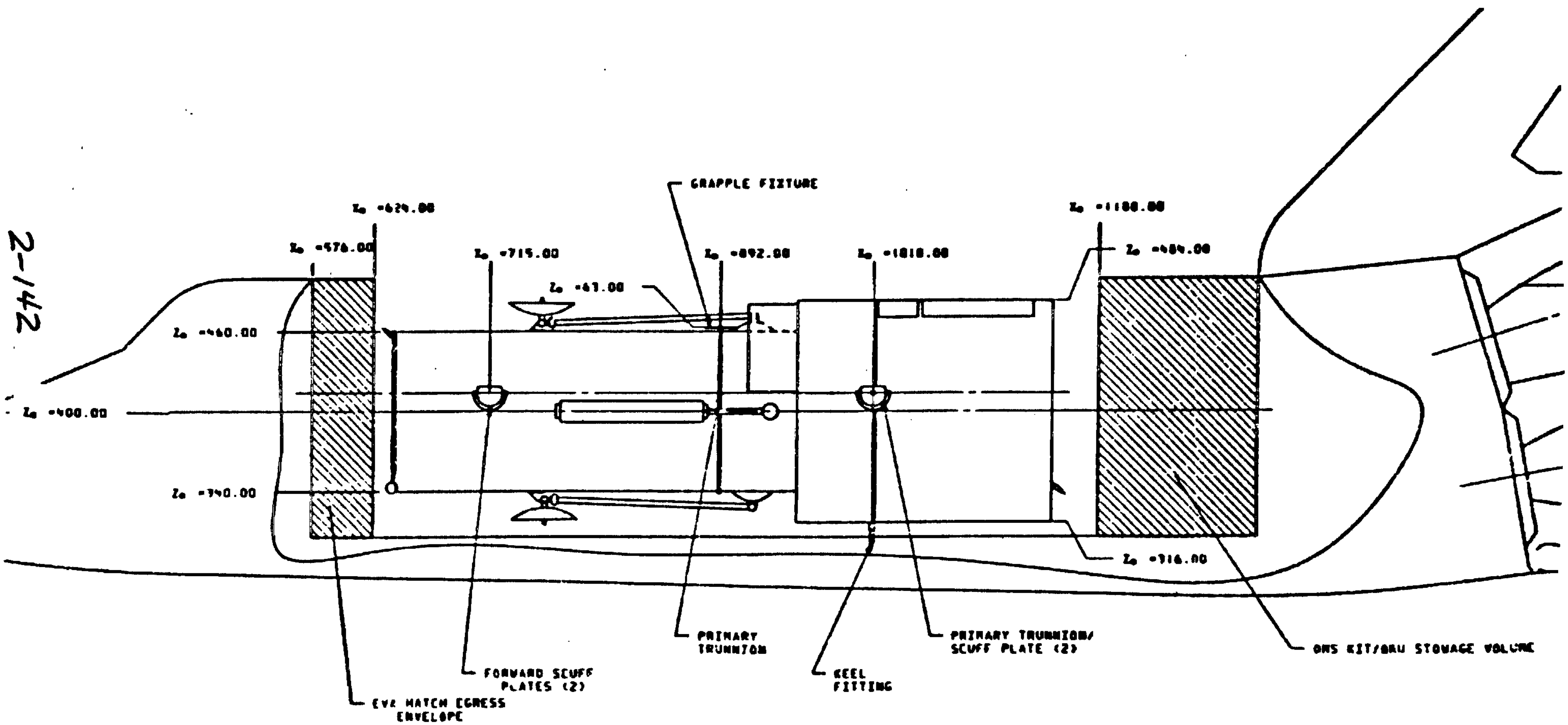
- o DEPLOYMENT
- o UNSCHEDULED MAINTENANCE
- o IN ORBIT MAINTENANCE
  - SCHEDULED
  - CONTINGENCY
- o REBOOST
- o EARTH RETURN

ST LOCATION IN THE STS CARGO BAY

THE ST SIZE, WEIGHT, CENTER OF GRAVITY AND EXTRA VEHICULAR ACTIVITY (EVA) REQUIREMENTS COMBINED TO DEFINE THE LOCATION IN THE STS CARGO BAY. THE SPACE FROM THE STS FORWARD BULKHEAD TO ORBITER STATION X=627.00 IS REQUIRED FOR EVA ASTRONAUT EGRESS INTO THE CARGO BAY. STATION X=627.00 TO X= 1191.00 IS ALLOCATED TO THE ST AND ASSOCIATED SPACE SUPPORT EQUIPMENT (SSE) INCLUDING THE FLIGHT SUPPORT SYSTEM (FSS) PLATFORM REQUIRED ON THE MAINTENANCE MISSION. THE AREA FROM STATION X=1191.00 TO THE STS AFT BULKHEAD IS ALLOCATED TO THE ORBITAL MANEUVERING SYSTEM (OMS) KIT VOLUME AND ORBITAL REPLACEABLE UNIT (ORU) STORAGE.

FOR ALL MISSION INVOLVING THE ST, THE STS WILL BE REQUIRED TO CARRY ACTIVE SILL AND KEEL RETENTION LATCHES AS WELL AS POWER UMBILICAL PROVISIONS AT THE STATIONS INDICATED FOR A POSSIBLE EARTH RETURN.

ST LOCATION IN STS CARGO BAY

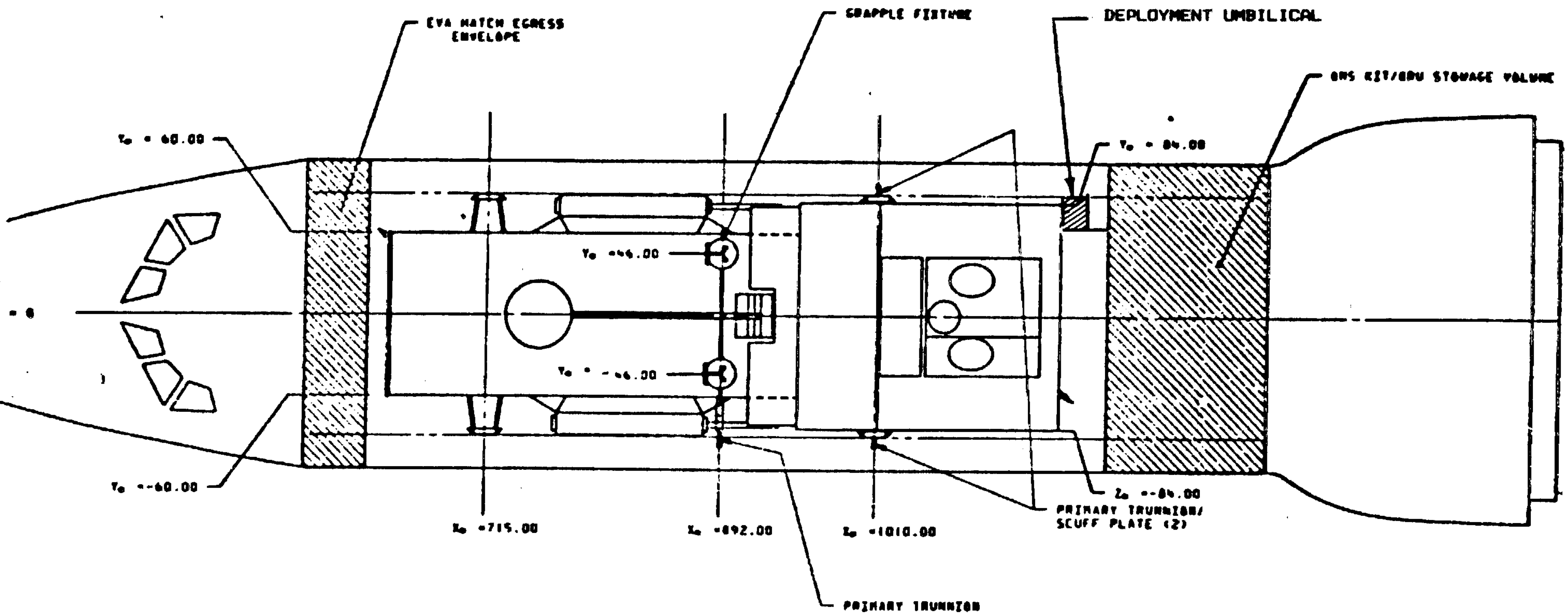


ST/STS INTERFACES

THIS TOP VIEW OF THE ST IN THE STS CARGO BAY ILLUSTRATES THE MECHANICAL AND ELECTRICAL INTERFACES REQUIRED FOR DEPLOYMENT AND RETRIEVAL OPERATIONS.

ST IS UNSTOWED FROM THE CARGO BAY BY THE STS CREW WITH THE REMOTE MANIPULATOR SYSTEM (RMS). TWO GRAPPLE FIXTURES ARE INSTALLED ON THE MAIN RING OF THE FORWARD SHELL.

PAYLOADS WHICH DEPLOYABLE AND RETRIEVABLE REQUIRE SCUFF PLATES, THE AFT SCUFF PLATES ARE ATTACHED TO THE AFT TRUNNION (STA. X 1010) AND INTERFACE WITH HIGH RISE ACTIVE TRUNNION FITTINGS. THESE SCUFF PLATES ARE DESIGNED TO ROTATE TO ALLOW ACCESS TO THE FINE GUIDANCE SENSORS. FORWARD SCUFF PLATES PROTECT THE SOLAR ARRAYS AND INTERFACE WITH PASSOVER GUIDES MOUNTED ON THE ORBITER SILLS.



EVA HATCH EGRESS ENVELOPE
GRAPPLE FIXTURE
DEPLOYMENT UMBILICAL
ORS KIT/ORU STOWAGE VOLUME
Yo = 60.00
Yo = 84.00
Yo = 46.00
Yo = 0
Yo = -46.00
Yo = -60.00
Zo = -84.00
PRIMARY TRUNNION/ SCUFF PLATE (2)
Xo = 715.00
Xo = 892.00
Xo = 1010.00
PRIMARY TRUNNION

ST DEPLOYMENT REQUIREMENTS

THE ST, LIKE ANY OTHER PAYLOAD, HAS UNIQUE DEPLOYMENT REQUIREMENTS.

OF PARTICULAR IMPORTANCE IS THE CONTROL OF STS GENERATED CONTAMINATION SOURCES.

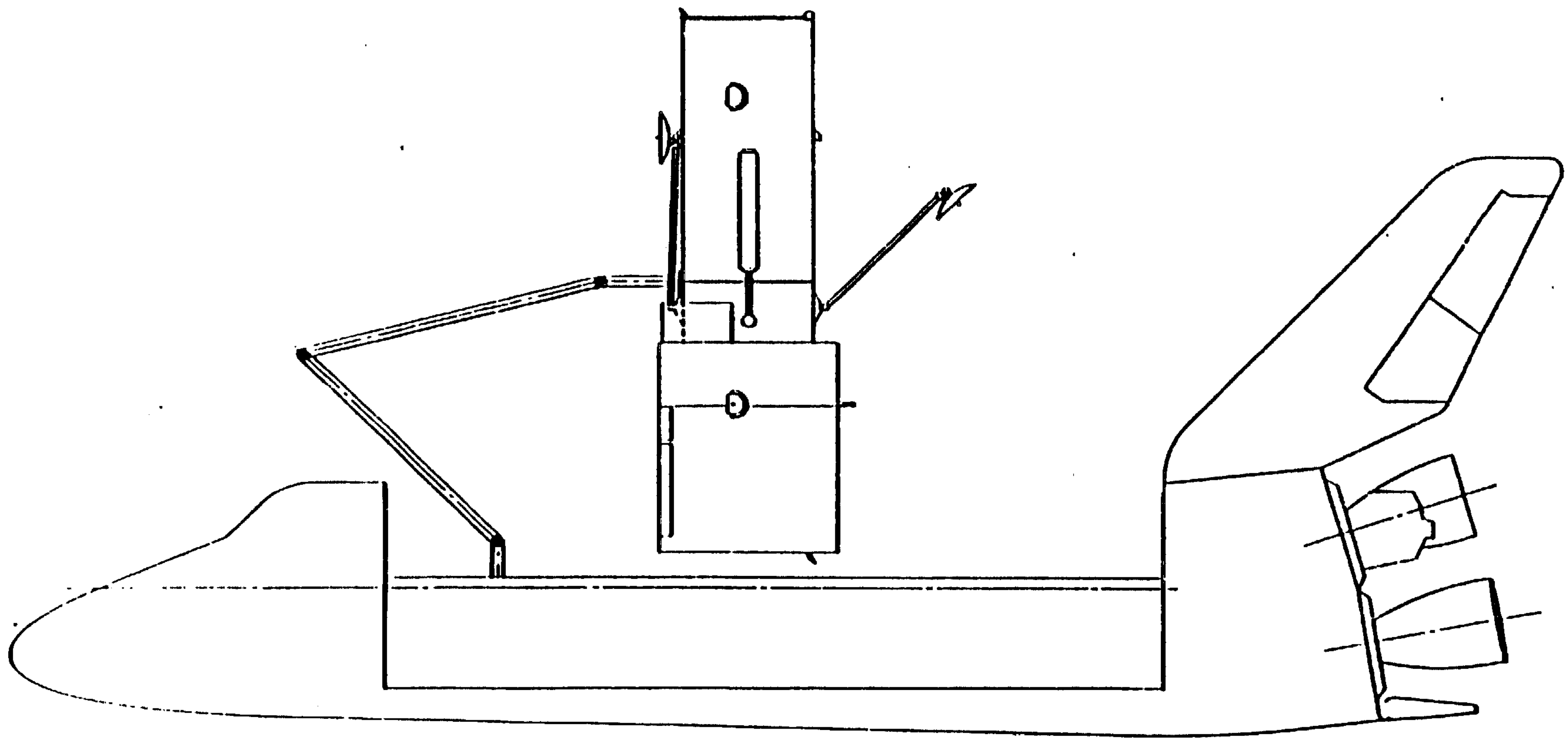
ST DEPLOYMENT REQUIREMENTS

- o DIRECT INSERTION TO 320 NM @ 28.5 INCLINATION
- o DEPLOYMENT ON SECOND ORBITAL DAY TO REDUCE CREW WORKLOAD IN PREPARATION FOR UNSCHEDULED MAINTENANCE EVA
- o DEPLOYMENT OF SOLAR ARRAYS AND HIGH GAIN ANTENNAS IN ADDITION TO UNLATCHING OF THE APERTURE DOOR, MUST BE VERIFIED PRIOR TO RELASE BY RMS
- o AT SEPARATION THE VECTOR SUM OF THE RATES IMPARTED TO THE ST MUST NOT EXCEED 0.1 DEGREE/SECOND
- o SELECTED FIRING OF SHUTTLE ENGINES AT SEPARATION IS REQUIRED TO CONTROL CONTAMINATION LEVELS

UNSCHEDULED MAINTENANCE

AFTER THE PAYLOAD RETENTION SYSTEM IS RELEASED AND UMBILICAL IS DISCONNECTED, THE ST WILL BE LIFTED FROM THE CARGO BAY AND HELD ON THE RMS FOR DEPLOYMENT OF THE SOLAR ARRAYS, HIGH GAIN ANTENNAS, APERTURE DOOR UNLATCHING AND A BRIEF SYSTEM CHECK-OUT.

AN UMBILICAL DISCONNECT FAILURE OR AN APPENDAGE DEPLOYMENT FAILURE WILL REQUIRE AN EVA TO OVERRIDE THE FAILED SYSTEM. TWO CREW MEMBERS WILL BE PREPARED FOR RAPID RESPONSE TO THIS UNSCHEDULED MAINTENANCE BY DONNING THEIR SPACE SUITS AND COMPLETING PREBREATHING DURING THE DEPLOYMENT SEQUENCE.



ST RENDEZVOUS INTERFACES

THE USEFUL LIFE OF THE ST WILL BE ENHANCED BY AN ORBIT MAINTENANCE. TO CARRY OUT THIS MAINTENANCE THE STS MUST RENDEZVOUS IN ORBIT WITH THE ST. THE ST DESIGN INCORPORATES THE RENDEZVOUS INTERFACES DEFINED IN JSC ICD-19001 CORE ICD.

ST RENDEZVOUS INTERFACES

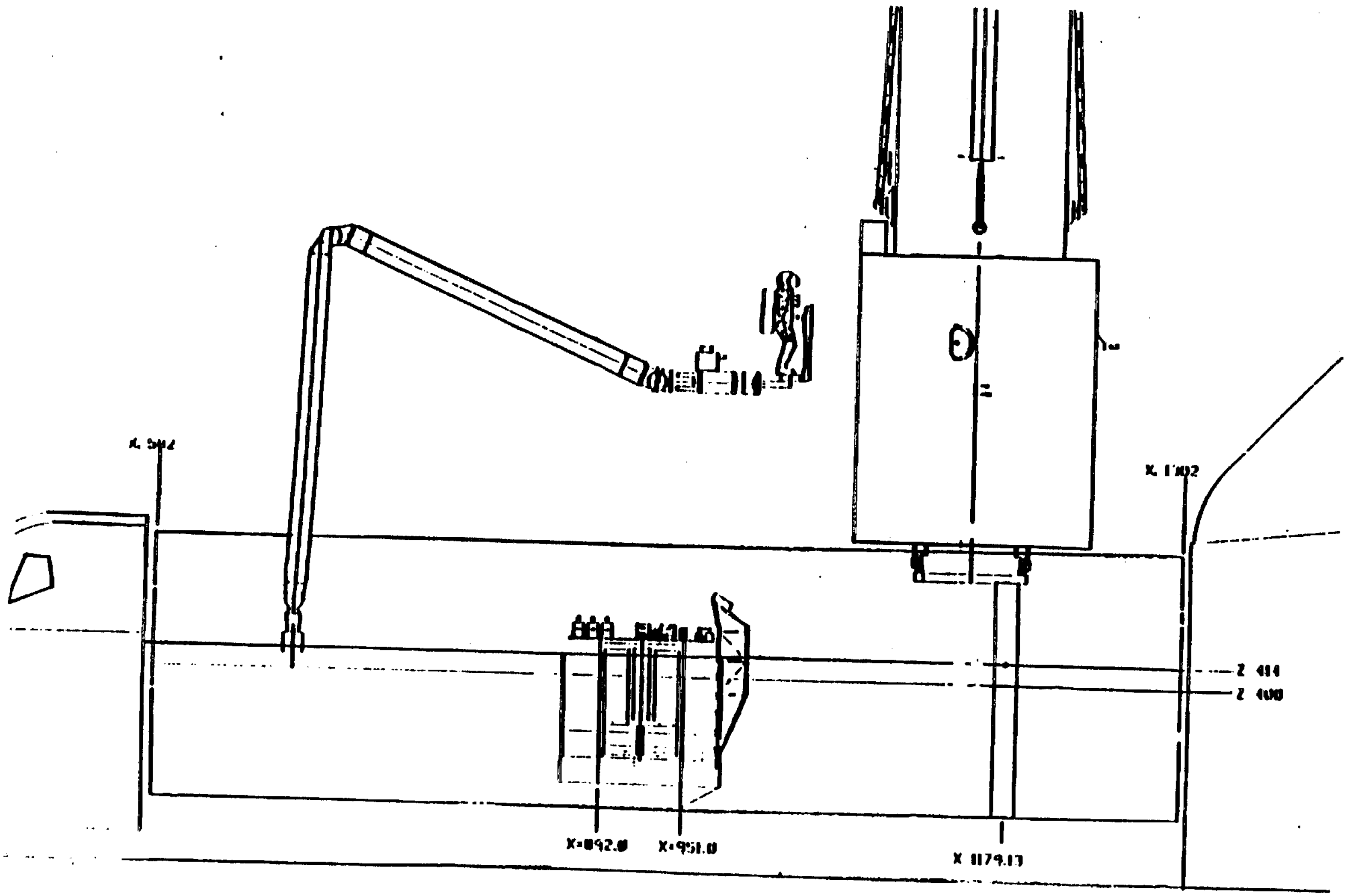
- ST PRESENTS A 4033 M^2 AVERAGE EFFECTIVE RADAR CROSS SECTION UTILIZED FOR INITIAL TRACKING.
- ST SURFACES ARE HIGHLY SPECULAR (93%) UNDER ANY SUN CONDITIONS ALLOWING DETECTION OF UP TO 5 MILES.
- THE ORBITER OVERHEAD LIGHTS ALLOW THE CREW TO EASILY DISCERN ST ORIENTATION. REFLECTORS ARE LOCATED ON THE ST + AND −V2 AXIS AS AN ORIENTATION AID.

SCHEDULED MAINTENANCE

SCHEDULED MAITENANCE MISSIONS WILL OCCUR EVERY 2.5 YEARS. DURING THIS MISSION A FULL COMPLEMENT OF ORBITAL REPLACEABLE UNITS (ORU's) FROM BATTERIES AND RATE SENSOR UNITS TO SCIENTIFIC INSTRUMENT AND SOLAR ARRAYS WILL BE CHANGED OUT IN ORBIT DURING THREE 6 HR. EVA's.

SCHEDULED MAINTENANCE REQUIRES AN ORU CARRIER AND THE FLIGHT SUPPORT SYSTEM (FSS). THE RMS WILL BE UTILIZED TO TRANSER ORU's.

LOAD CONSTRAINTS REQUIRE THAT THE PRCS MOTOR BE INHIBITED WHILE THE ST IS IN THE VERTICAL POSITION ON THE FSS.

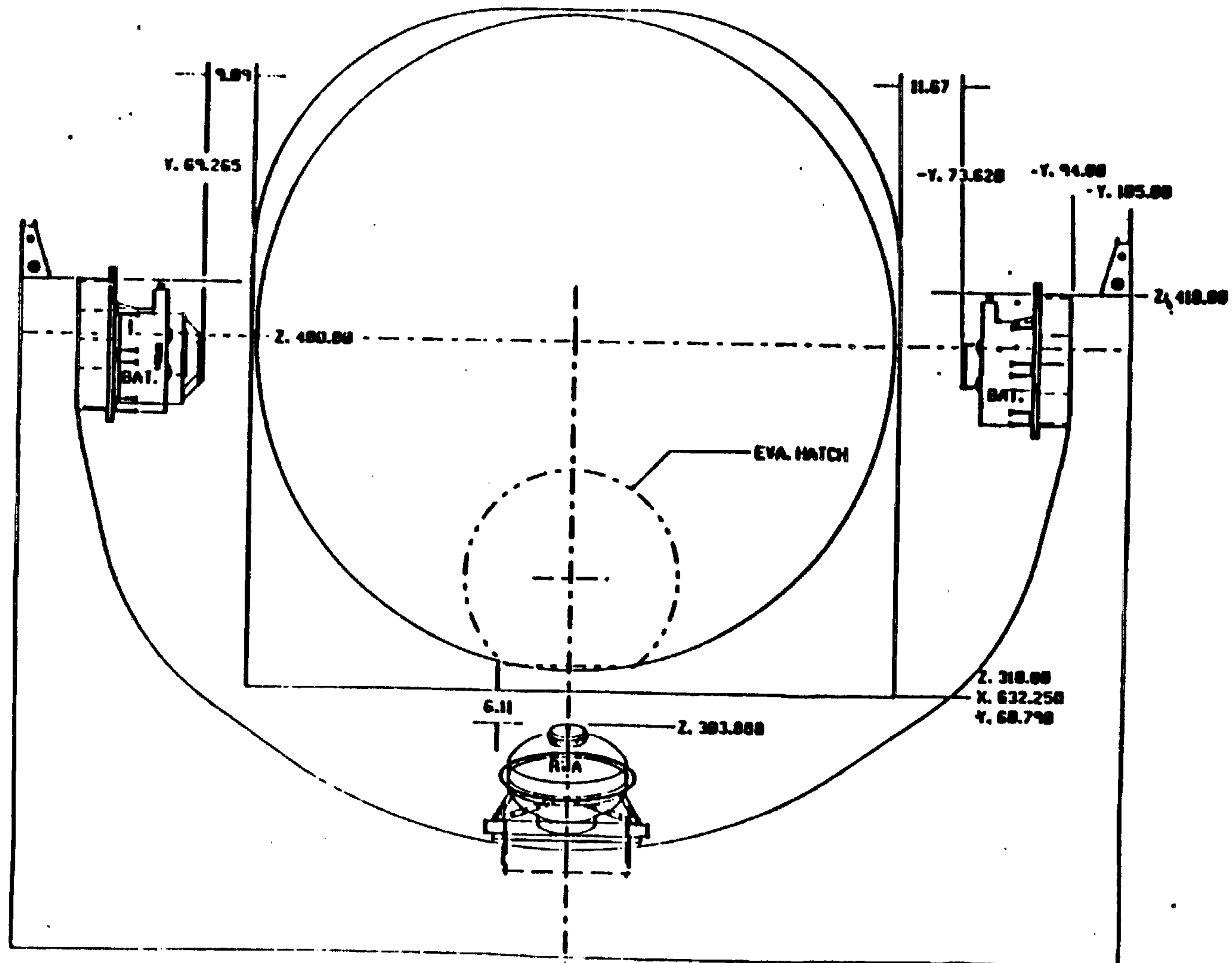

X 582
X 1202
Z 414
Z 400
X=892.0
X=951.0
X 1179.13

CONTINGENCY MAINTENANCE

CONTINGENCY MAINTENANCE IS A NEW CONCEPT TO THE ST PROGRAM IN WHICH A LIMITED, SINGLE 6 HR EVA, WILL BE USED TO REPLACE SMALLER ORUs.

THIS MISSION WILL SHARE THE PAYLOAD BAY WITH OTHER EXPERIMENTS OR SATELLITES. THE SPACE SUPPORT EQUIPMENT IS LIMITED TO SUPPORT STRUCTURE WHICH WILL BE MOUNTED ON THE ORBITER SILL.

ALL SERVICING IS DONE WITH ST ATTACHED TO THE RMS.

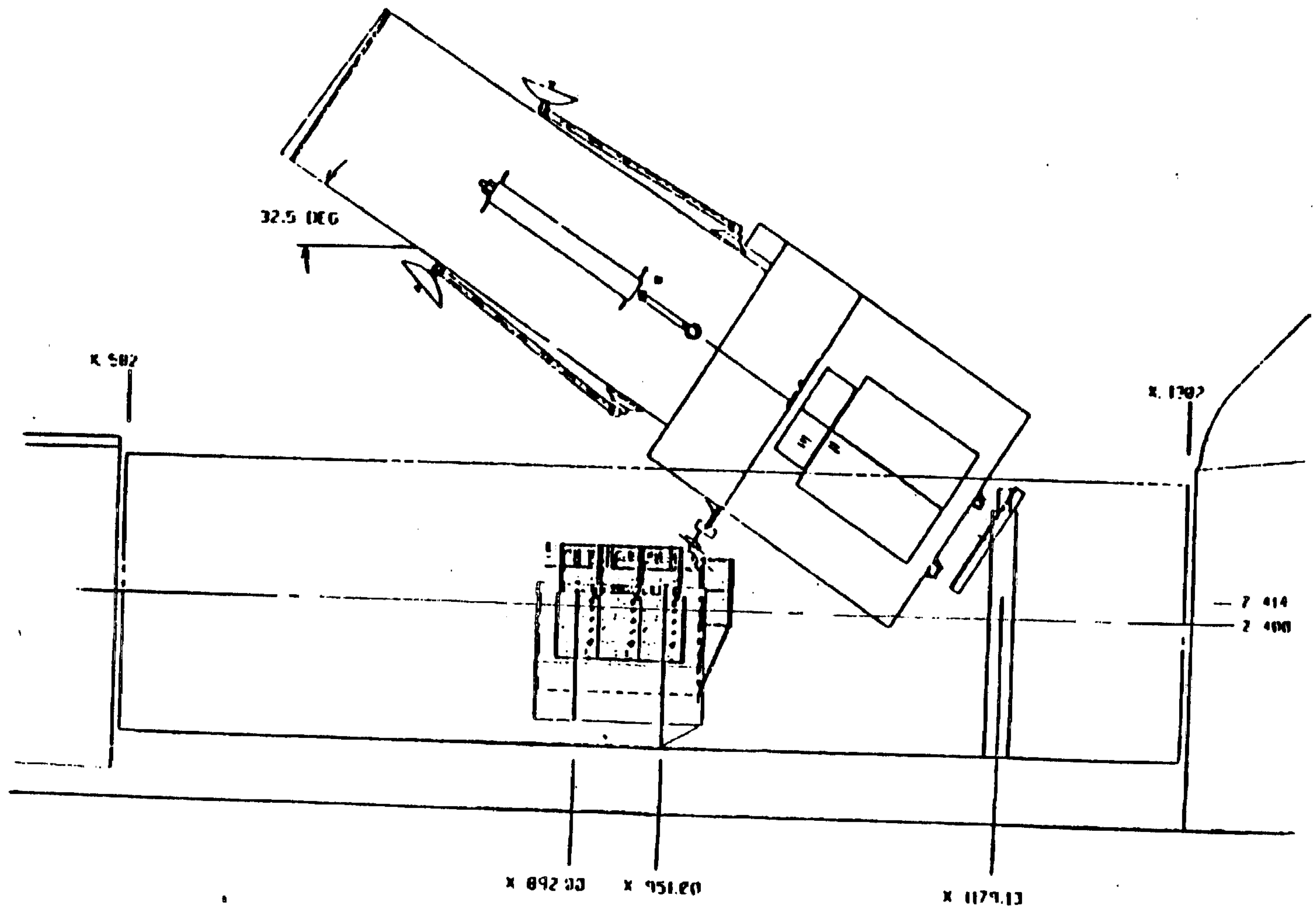


END VIEW-LOOKING AFT

REBOOST

ANOTHER FACTOR OF EXTENDING THE USEFUL ORBITAL OF ST WILL BE COMPENSATION FOR LONG TERM ORBITAL DECAY BY REBOOST. ILLUSTRATION SHOWS A REBOOST OF THE ST DURING A MAINTENANCE MISSION WHERE IT IS LATCHING TO THE ORU CARRIER AND FSS FOR PRCS FIRING.

THIS IS THE SAME CONFIGURATION REQUIRED FOR OVERNIGHT STOWAGE DURING A MAINTENANCE MISSION.



32.5 DEG
X 582
X 1302
Z 414
Z 400
X 892.00
X 951.80
X 1179.13

EARTH RETURN

ON ANY ST MISSION MAY REQUIRE AN EMERGENCY EARTH RETURN

EARTH RETURN

- ST STOWED IN CARGO BAY
- EVA TO CONNECT UMBILICAL
- APPENDAGES ARE JETTISONED IF THEY FAIL TO LATCH
- DURING A MAINTENANCE MISSION THE ORU CARRIER MUST BE JETTISONED

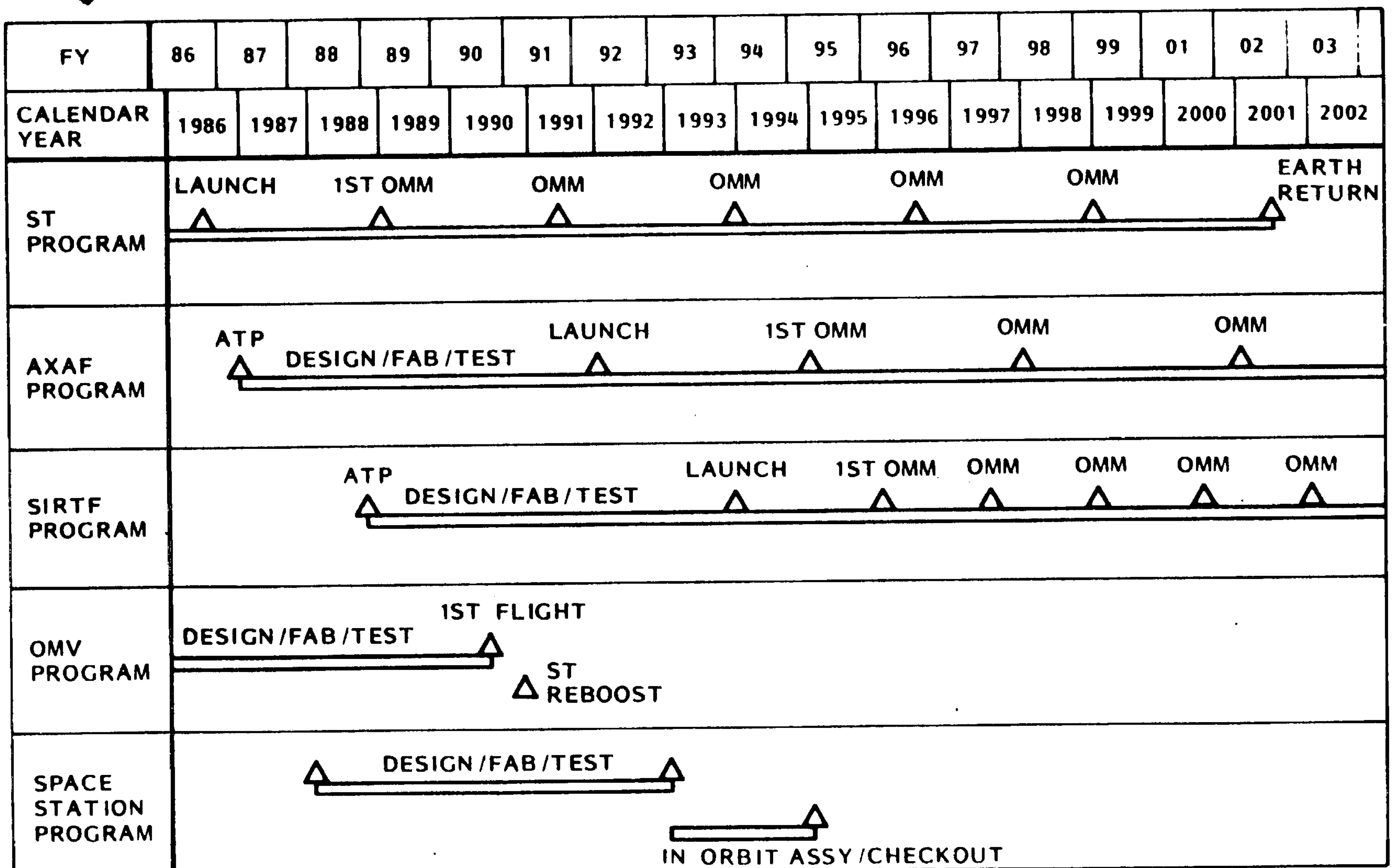
- ST/OMV/SPACE STATION

INTEGRATED SCHEDULE

THE SPACE TELESCOPE, ADVANCED X-RAY ASTRONOMICAL FACILITY (AXAF) AND SPACE INFRARED TELESCOPE FACILITY (SIRTF) ARE ALL LONG DURATION ASTRONOMICAL STAELLITES WHICH ARE BASELINED WITH AN ORBITAL MAINTENANCE REQUIREMENT.

THIS SCHEDULE INTEGRATES THE ORBITAL MAINTENANCE PLANNING TO SUPPORT THESE SATELLITE SYSTEMS. IT ALSO INTRODUCES THE ORBITAL MANUEVERING VEHICLE (OMV) AND SPACE STATION, TWO IMPORTANT ELEMENTS OF FUTURE SATELLITE SERVICING.

INTEGRATED SCHEDULE



ST / OMV ORBIT TRANSFER OPERATIONAL REQUIREMENTS

THE OMV MUST HAVE THE CAPABILITY OF PERFORMING ORBIT TRANSFERS OF THE ST WITH APPENDAGES STOWED OR DEPLOYED. UNDER ANY CONDITIONS THE OMV MUST PERFORM ORBITAL OPERATIONS IN A MANNER THAT WILL NOT CONSTRAIN THE ST PERFORMANCE.

ST ORBIT TRANSFER MISSIONS

- ORBIT INJECTION: (DEPLOYMENT)
  OMV MUST TRANSFER ST FROM AN STS 160 NM ORBIT TO A 320 NM OPERATION ORBIT

- REBOOST:
  OMV MUST TRANSFER ST FROM A 215 NM ORBIT TO A 380 NM ORBIT OR HIGHER

- RETRIEVAL:
  OMV MUST RETRIEVE ST FROM A 380 NM OR HIGHER ORBIT AND TRANSFER TO AN STS 160 NM ORBIT

POTENTIAL OMV BERTHING ATTACHMENTS

THE ST IS CURRENTLY DESIGNED TO INTERFACE WITH THE STS TRUNNION AND KEEL LATCHES, THE RMS AND EFFECTOR AND THE FSS LATCHES AND UMBILICAL. THESE STRUCTURAL INTERFACES WERE REVIEWED FOR POTENTIAL OMV INTERFACE.

POTENTIAL OMV BERTHING ATTACHMENTS

ST/STS TRUNNIONS (3 GRAPPLE POINTS)

- HEAVY FITTINGS IN OFF-CENTERLINE PLANE PARALLEL TO LONGI-TUDINAL AXIS
- POSSIBILITY OF DAMAGING ORBITER INTERFACE HARDWARE
- NO TARGET PROVISION FOR USE IN BERTHING CONTROL

ST/RMS GRAPPLE FIXTURE

- INSTALLATION IS DESIGNED FOR "BERTHING" WITH RMS
- LOCATION IS SIDE-MOUNTED, OFF CENTERLINE
- CENTER OF AFT BULKHEAD NOT AVAILABLE FOR GRAPPLE FIXTURE DUE TO INTERFERENCE WITH FSS

ST/FSS LATCHES (3)

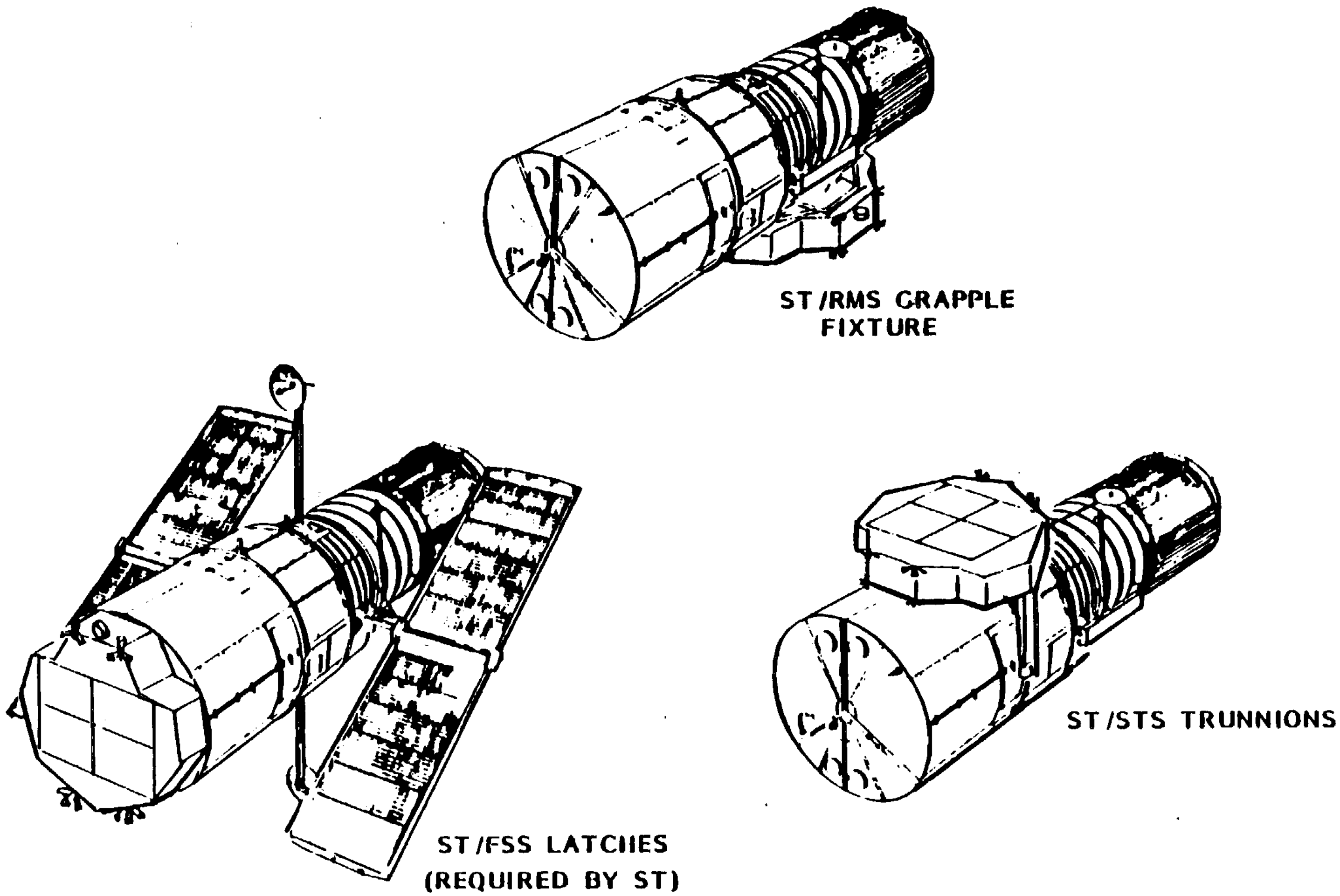
- INSTALLATION IS DESIGNED FOR BERTHING WITH FSS
- THREE FSS LATCHES HAVE SOME SNARE/CAPTURE CAPABILITY
- MOST "NATURAL" BOOSTER INTERFACE, ALLOWING TOTAL NON-INTERFERENCE WITH ANY OF ST DEPLOYABLES

BERTHING OMV TO ST

THE ILLUSTRATION SHOWS EXAMPLES OF THE OMV BERTHED TO EACH OF THE THREE EXISTING STRUCTURAL INTERFACES.

NOTE THAT THE ST/FSS LATCH INTERFACE IS THE ONLY CONFIGURATION WHICH ALLOWS ATTACHMENT WITH APPENDAGES STOWED OR DEPLOYED. THIS REQUIREMENT IS ST RETRIEVAL IN WHICH AN APPENDAGE MAY FAIL TO RETRACT.

BERTHING OMV TO ST



ST ORBIT TRANSFER MISSIONS

A CRITICAL FACTOR IN THE DESIGN OF THE OMV IS DEVELOPING ORBITAL TRANSFER REQUIREMENTS. FOR THE ST INTERFACE THIS MEANS ESTABLISHING THE REQUIREMENTS WHICH DEFINE THE MAXIMUM NUMBER OF ORBIT TRANSFERS AS WELL AS THE MAXIMUM ORBIT RANGES.

THE ORBIT TRANSFERS REPRESENT CONDITIONS FOR ST ORBIT INJECTION (DEPLOYMENT), RE-BOOST AND RETRIEVAL.

ST/OMVORBIT TRANSFER

OPERATIONAL REQUIREMENTS

- THE OMV MUST HAVE THE CAPABILITY OF VERIFYING CONDITION OF ST AND LATCHED STOWED APPENDAGES PRIOR TO BERTHING, ORBIT TRANSFER, AND RELEASE FROM MISSION

- WITH ST APPENDAGES DEPLOYED OMV MUST HAVE THE FOLLOWING CAPABILITIES:
  - REMOTE OR EVA CAPABILITY TO OVERRIDE AND LATCH APPENDAGES
  - THRUST LIMITED TO 0.002 G, IN ANY DIRECTION, THE MAXIMUM LOADING FOR DEPLOYED SOLAR ARRAYS

- AN OPERATIONAL FAILURE OF OMV WILL NOT DAMAGE ANY ST SYSTEM (I.E., A THRUSTER FAILURE WHICH COULD DAMAGE A DEPLOYED APPENDAGE)

ADDITIONAL ST / OMV INTERFACE REQUIREMENTS

THE FOLLOWING ARE ADDITIONAL ST / OMV INTERFACE REQUIREMENTS:

- THERMAL
- POWER
- EVA

BERTHING / SEPARATION

COMMUNICATIONS

CONTAMINATION

ADDITIONAL ST/OMV INTERFACE REQUIREMENTS

THERMAL

- o ST MUST BE MAINTAINED IN A NOMINAL SUN POSITION 50 DEGREES OFF VEHICLE CENTERLINE
- o EXACT ST THERMAL INTERFACE WITH OMV MUST BE ESTABLISHED

POWER

- o OMV MUST HAVE A CAPABILITY OF PROVIDING ST BETWEEN 400 WHR'S TO 12,000 WHR'S OF POWER FOR A 4-HOUR PERIOD
- o OMV PROVIDED POWER MUST BE MAINTAINED BETWEEN 24.6 VDC AND 35.0 VDC WITH 30 VDC TRANSIENT AND 0.75 VOLT RIPPLE
- o ST MUST BE TREATED AS A SINGLE POINT GROUND AT THE CONNECTOR INTERFACE

EVA

- o THE OMV MUST HAVE EVA SEPARATION COMPABILITY

ADDITIONAL ST / OMV INTERFACE REQUIREMENTS

THE FOLLOWING ARE ADDITIONAL ST / OMV INTERFACE REQUIREMENTS:

THERMAL

POWER

EVA

- BERTHING / SEPARATION
- COMMUNICATIONS
- CONTAMINATION

ADDITIONAL ST/OMV INTERFACE REQUIREMENTS (CONT'D)

BERTHING / SEPARATION

- o OMV MUST DUPLICATE THE SHUTTLE AND RMS BERTHING / SEPARATION REQUIREMENTS

COMMUNICATION

- o RF ENERGY INCIDENT ON THE ST DUE TO OMV COMMUNICATIONS MUST NOT EXCEED 1.0 V/METER (14 KHz TO 1 GHz) AND 2.5 VOLTS / METER (1 GHz TO 3 GHz)

CONTAMINATION

- o OMV MUST NOT PRODUCE PARTICULATE OR MOLECULAR CONTAMINATION THAT WOULD REDUCE ST PERFORMANCE

SPACE STATION SATELLITE SERVICING REQUIREMENTS

NASA'S COMMITMENT TO THE SPACE STATION PROGRAM IS AN IMPORTANT STEP IN INCREASING THE CAPABILITY OF SUPPORTING ON-ORBIT SERVICING OF SATELLITES.

DEVELOPMENT OF AN ON-ORBIT SERVICING CAPABILITY FROM THE SPACE STATION MUST CONSIDER A MULTITUDE OF INTERRELATED BASIC REQUIREMENTS.

SPACE STATION SATELLITE SERVICING REQUIREMENTS

- LOGISTIC STORAGE OF SERVICING ELEMENTS
  - SERVICING COMPONENTS
  - CONSUMABLES
  - TEST HARDWARE
- DEVELOPMENT OF A FAMILY OF ORBIT TRANSFER SYSTEMS FROM OMV TO SPACE TUGS
- MAINTENANCE OF ORBIT TRANSFER SYSTEMS
- STANDARDIZED SATELLITE SERVICING INTERFACES
  - DOCKING INTERFACE
  - UMBILICAL INTERFACES
  - CONSUMABLE TRANSFER SYSTEMS
  - COMPONENTS
- CREW TRAINING AND FAMILIARIZATION

SERVICING ST FROM SPACE STATION

UTILIZING THE SPACE STATION AS A SATELLITE SERVICE CENTER IS AN ATTRACTIVE OPTION TO THE ST OPERATIONAL GOALS. HOWEVER, LOGISTICS STORAGE REQUIREMENTS AND OPERATION INTERFACES MUST BE ANALYZED.

SERVICING ST FROM SPACE STATION

ADVANTAGE

- o ST SERVICING CAN BE PERFORMED INDEPENDENT OF STS AND FSS

CONCERNS

- o LOGISTIC STORAGE OF ORU'S ON OR NEAR STATION
  - TRANSFER OF ORU'S TO STATION DEPENDS ON STS SCHEDULE
  - VERIFICATION OF ORU STATUS DURING STORAGE
- o OPERATIONAL INTERFACE
  - LONG DURATION ATTACHMENT TO SPACE STATION
  - THERMAL IMPACT DERIVED FROM SPACE STATION ATTITUDE REQUIREMENTS
  - CONTAMINATION CONTROL

SERVICING ST FROM AN ADVANCED SERVICING FACILITY

AN ADVANCED SERVICING FACILITY COULD BENEFIT ST IN ORBIT MAINTENANCE BY PROVIDING EITHER A THERMALLY CONTROLLED ENVIRONMENT OR A "SHIRT SLEEVE" ENVIRONMENT. A FACILITY OF THIS TYPE WOULD REQUIRE A MAJOR PROGRAM COMMITMENT.

SERVICING ST FROM AN ADVANCED SERVICING FACILITY

ADVANTAGES

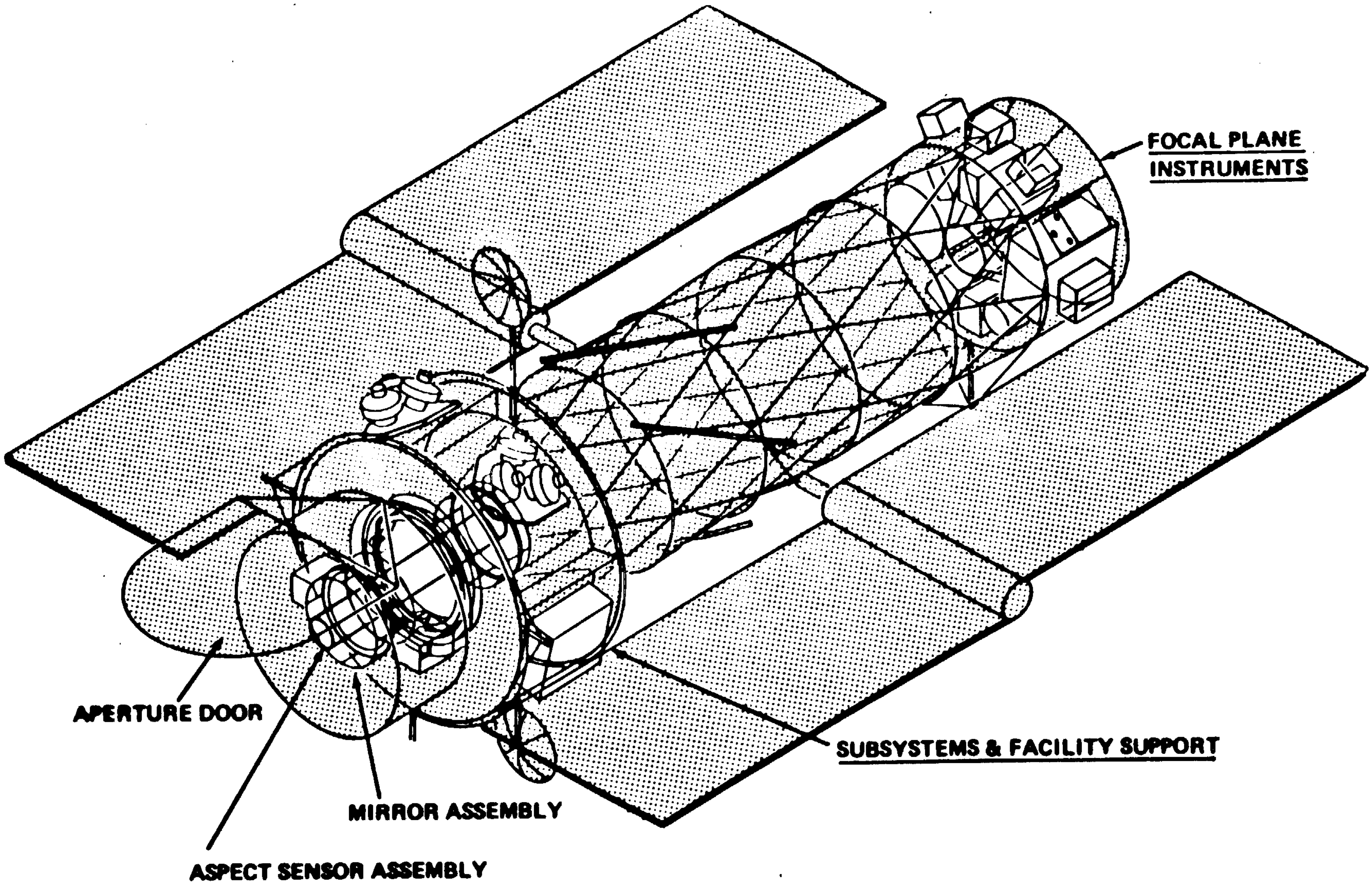
- A THERMAL STRUCTURE / HANGER WOULD REDUCE POWER CONDITIONING REQUIREMENT TO MAINTAIN ST THERMAL ENVIRONMENT
- REMOTE MANIPULATORS, SIMILAR TO THOSE USED IN HANDLING HAZARDOUS MATERIALS, WOULD REDUCE EVA REQUIREMENTS AND INCREASE COMPONENTS CHANGE OUT CAPABILITY
- A PRESSURIZED WORK FACILITY IN ORBIT WOULD ENHANCE PERFORMANCE OF COMPLEX TASKS
  - VEHICLES CAN BE POWERED DOWN DURING MAINTENANCE
  - COMPONENTS, TO A PRINTED CIRCUIT CARD LEVEL, CAN BE REPLACED IN ORBIT

CONCERNS

- APPROACH REQUIRES AN EXTENSIVE COMMITMENT OF SPACE STATION ARCHITECTURE
  - MULTI PROGRAM LOGISTICS STORAGE
  - MULTI PROGRAM CHECK-OUT EQUIPMENT
  - STORAGE AND REPLENISHMENT OF CONSUMABLES

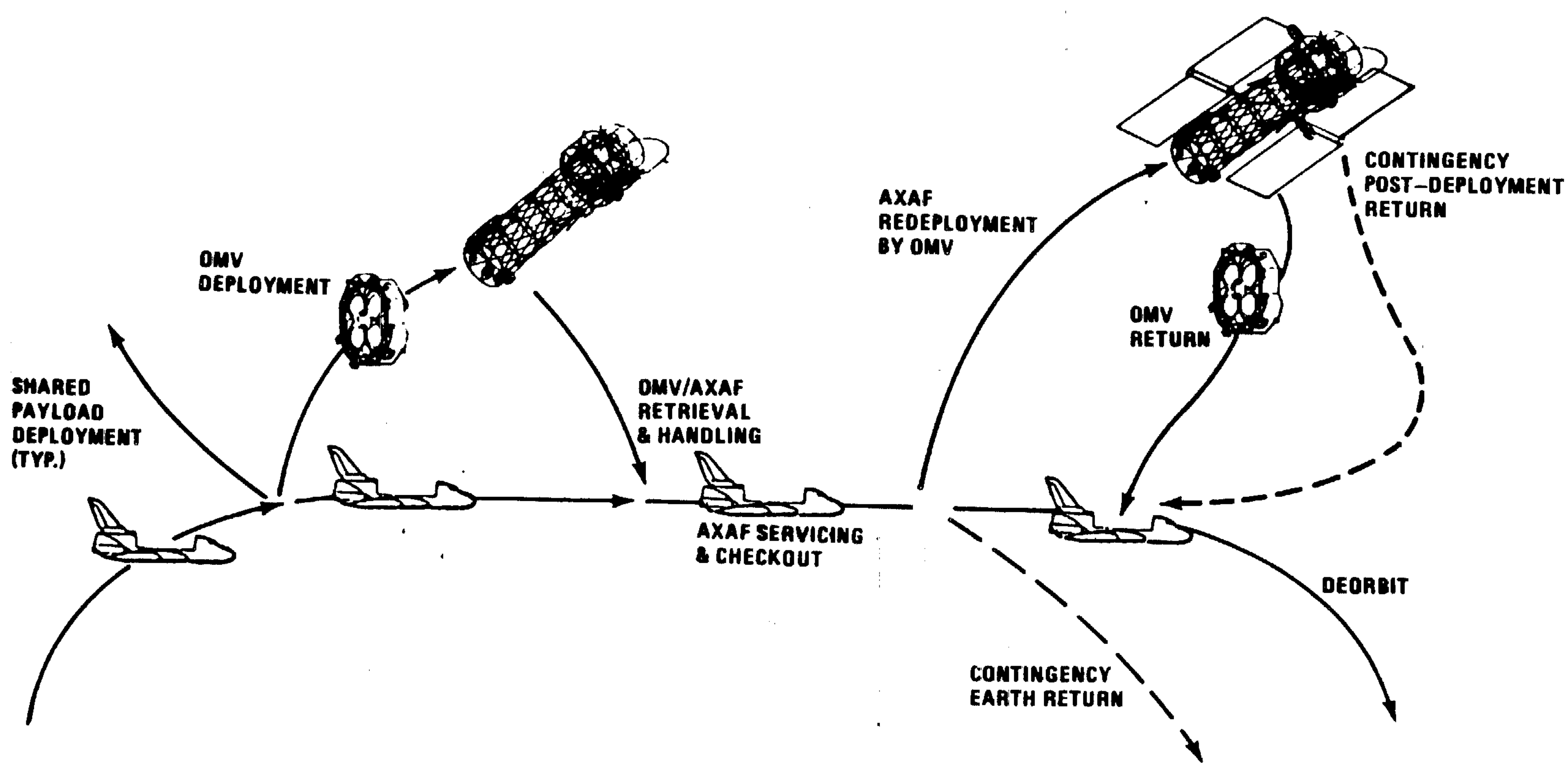
ADVANCED X–RAY ASTROPHYSICAL FACILITY

– SERVICING MISSION CONCEPTS –



AXAF CONFIGURATION D

AXAF SERVICING MISSION CONCEPT

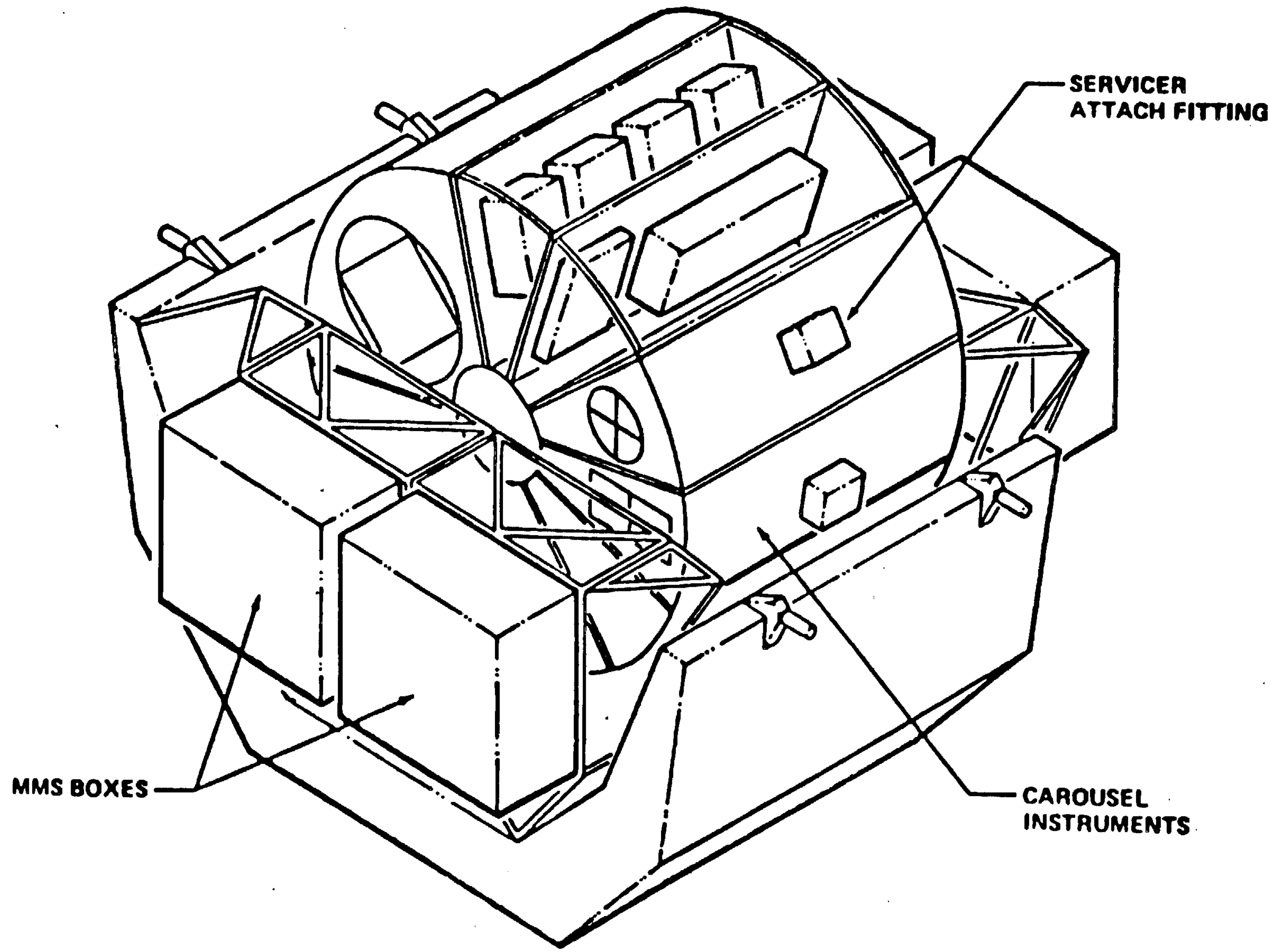


AXAF M/R MISSION

SHUTTLE PAYLOAD WEIGHT AND CG SUMMARY

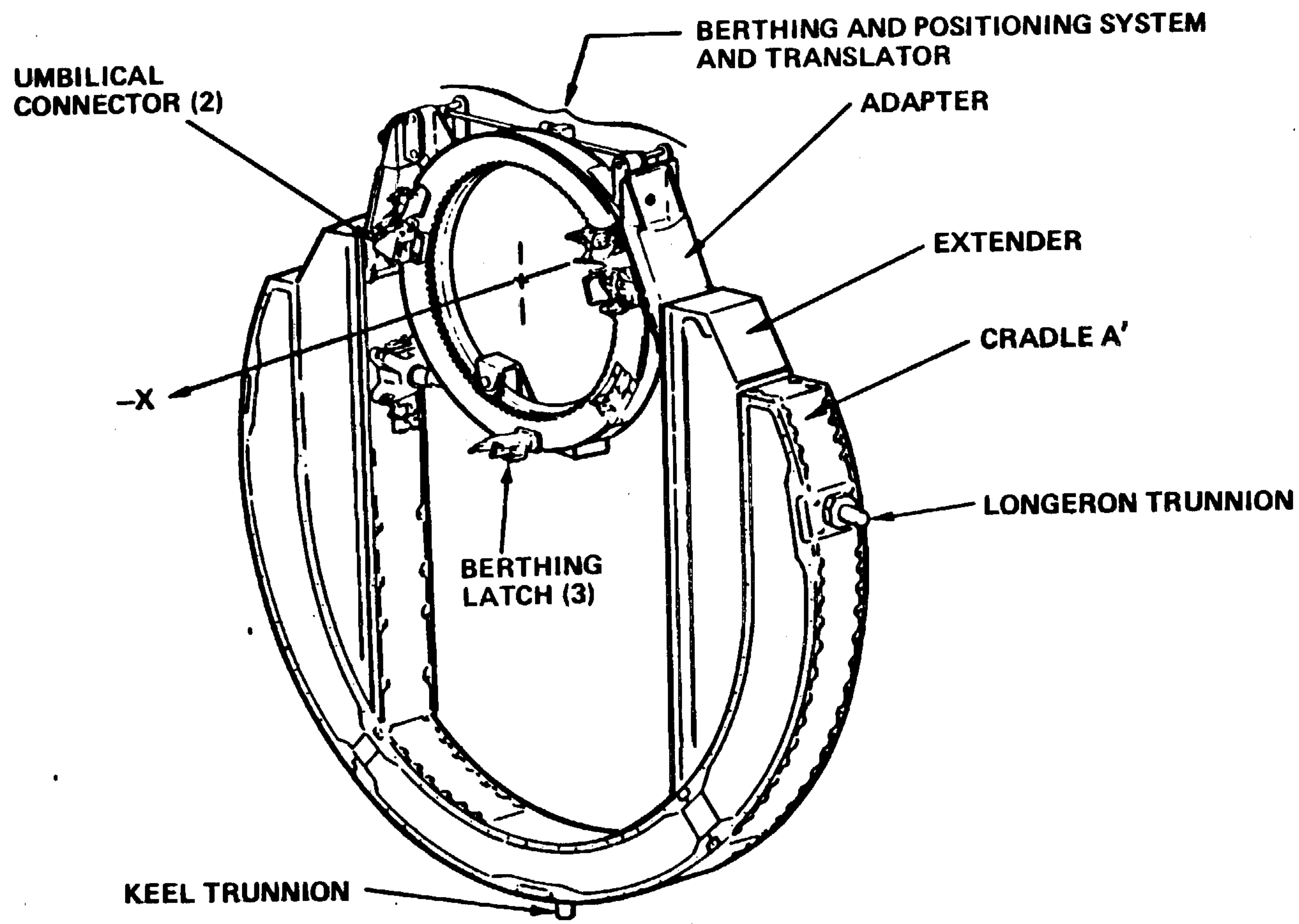
DESCRIPTION	LAUNCH WEIGHT (LBS)	LANDED WEIGHT (LBS)	XCG (FT)	YCG (FT)	ZCG (FT)
*1 ORU PALLET	1640.00	1640.00	39.10	0.00	0.0
2 ATTACH FITTINGS	746.00	746.00	39.10	0.00	0.0
*3 SCIENCE INSTRUMENTS	1707.00	1707.00	39.10	0.00	0.0
*4 SERVICER CAROUSEL	548.00	548.00	39.10	0.00	0.0
*5 SUBSYSTEMS BOXES & SU	1628.00	1628.00	39.10	0.00	0.0
6 A' CRADLE	3697.00	3697.00	53.70	0.00	0.0
7 ATTACH FITTINGS	466.00	466.00	53.70	0.00	0.0
8 OMV	10500.00	3800.00	30.10	0.00	0.0
9 ATTACH FITTINGS	1210.00	1210.00	30.10	0.00	0.0
10. AXAF ATTACH FITTINGS	1210.00	1210.00	32.00	0.00	0.0
11 ALLOWANCE ATTACH FIT	–675.00	–675.00	32.00	0.00	0.0
LAUNCH TOTALS	22677.00		36.97	0.00	0.00
LANDED TOTALS		16652.00	39.53	0.00	0.00
LESS JETTISON		–5523.00			
PLUS AXAF		+19355.00			
CONTINGENCY RETURN LANDED		30484.00			

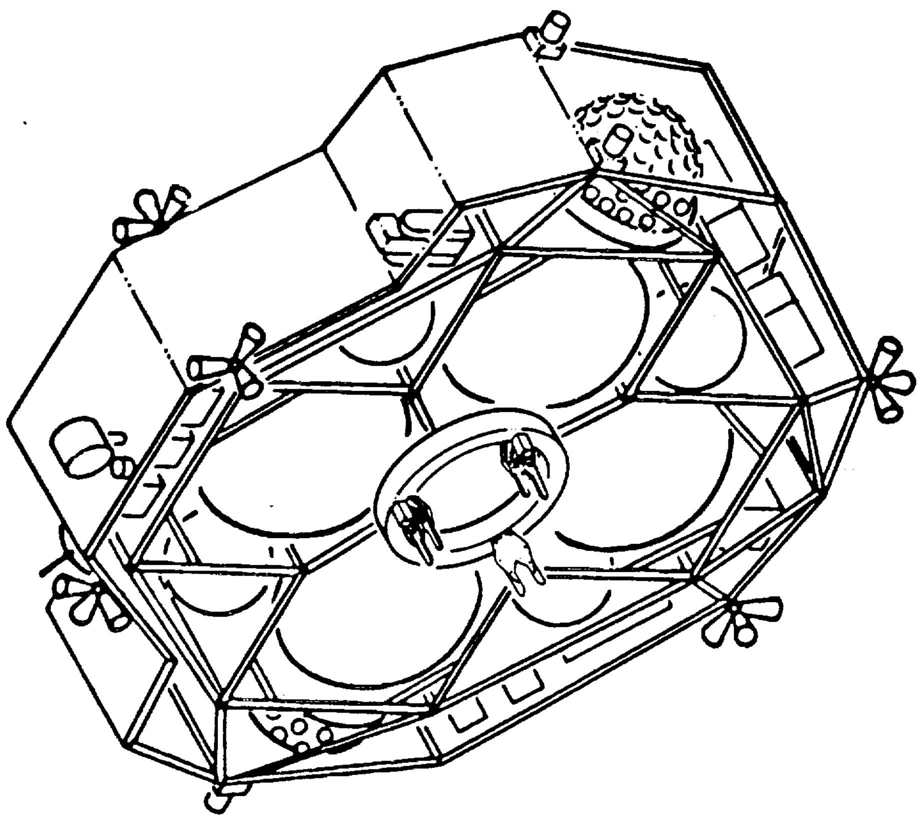
AXAF ORBITAL REPLACEMENT UNIT (ORU) CARRIER



2664–84

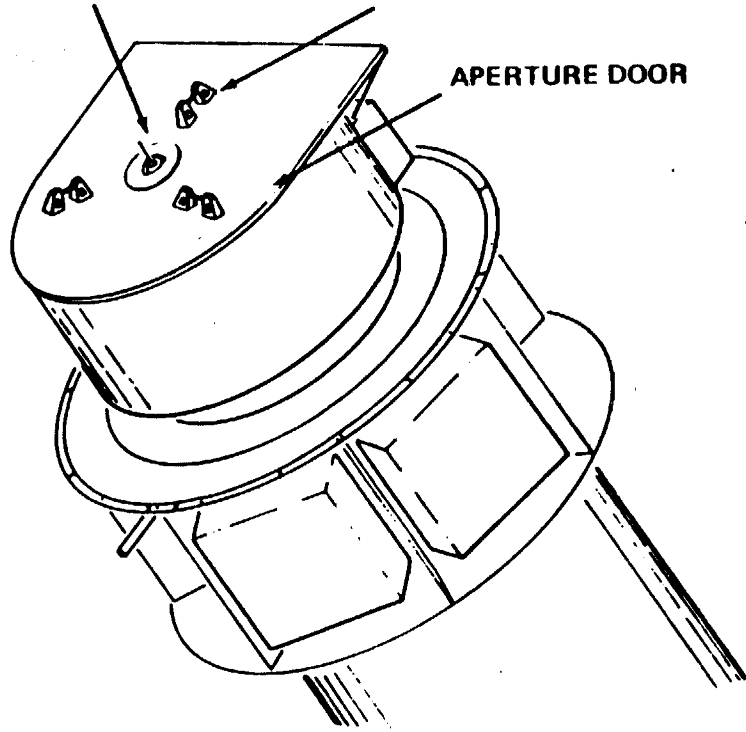
CRADLE A'

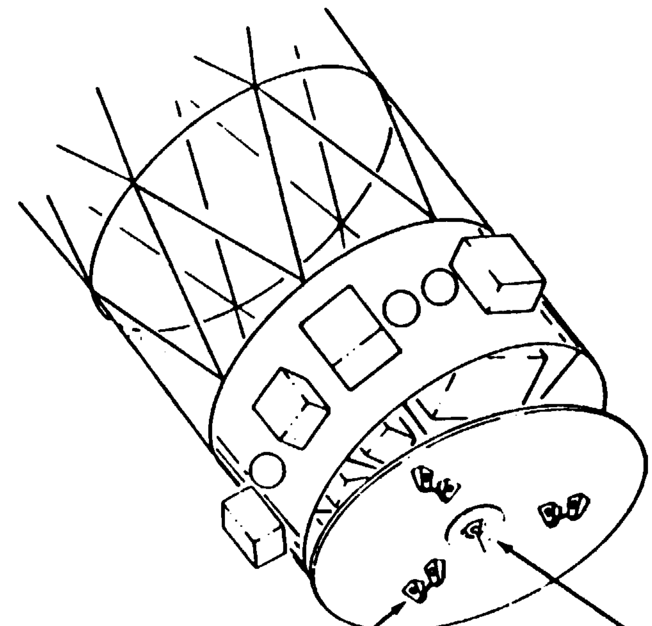




OMV

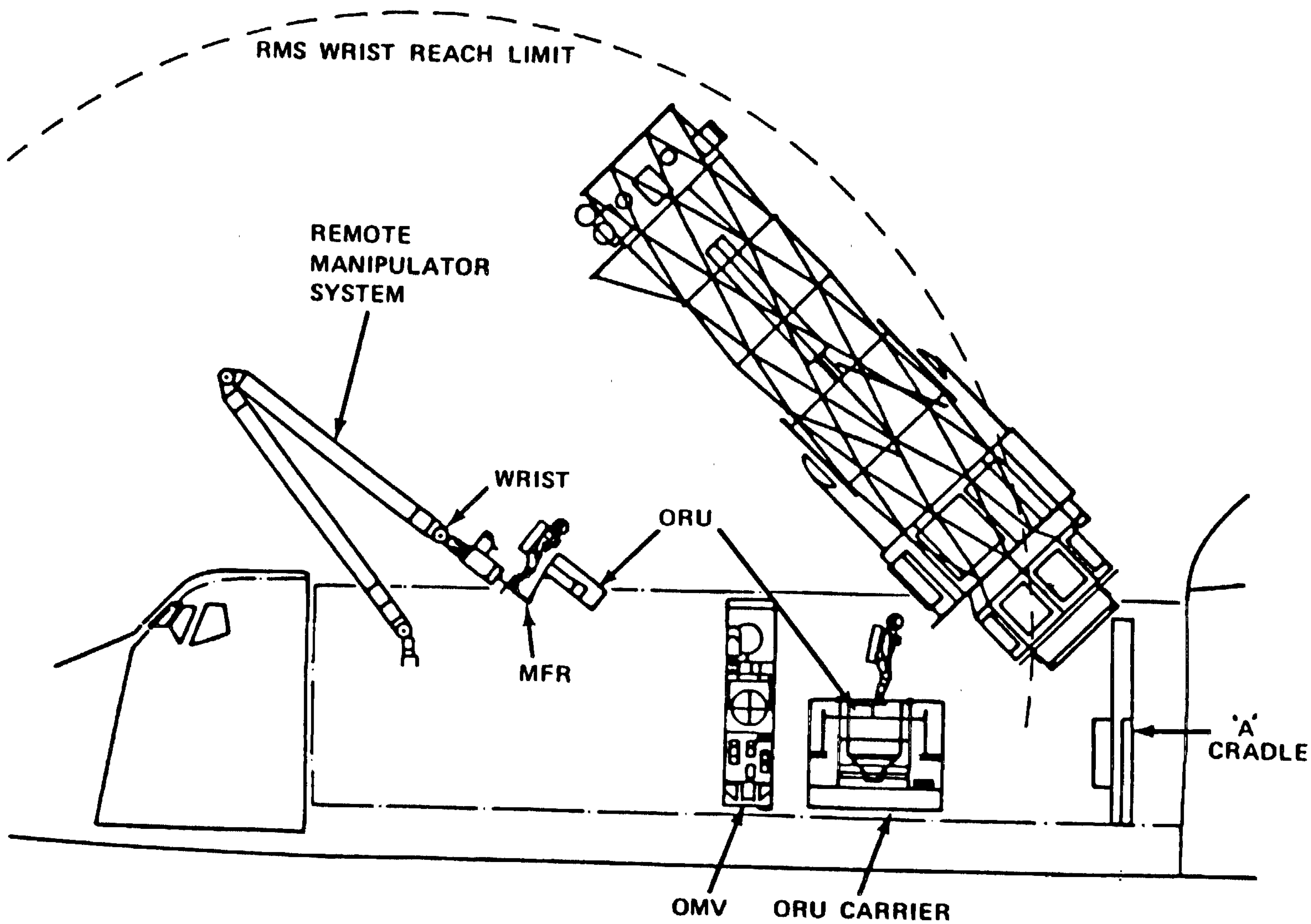
OMU/AXAF ATTACH FITTINGS





651-85

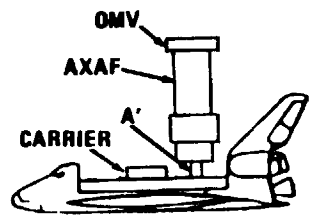
AXAF MAINTENANCE MISSION
AFT-BAY MAINTENANCE OPERATIONS



8932-83

AXAF MAINTENANCE MISSION
REPRESENTATIVE PAYLOAD BAY OPERATIONS SUMMARY

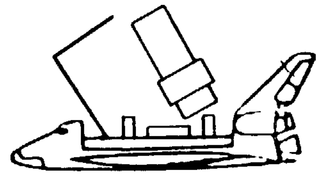
①



AXAF/OMV BERTHING

- AXAF MATED TO A' BY RMS
- A' UMBILICAL CONNECT
- RMS RELEASES AXAF

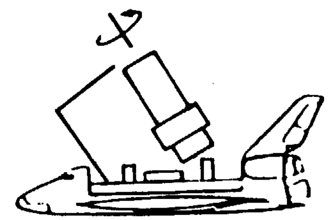
②



OMV BERTHING

- A' TILTS AXAF
- RMS GRAPPLES OMV
- OMV RELEASES AXAF
- RMS BERTHS OMV
- OMV UMB. CONNECT

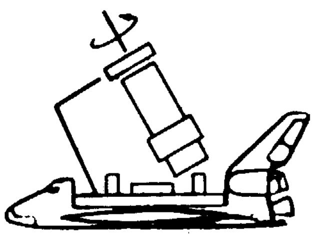
③



EXTERNAL ORU OPNS

- EVA + RMS/MFR SEQUENTIAL REPLACEMENT OF SUBSYSTEM RING ORUS 12–15
  - POTENTIAL DIRECT ACCESS FROM CARRIER
- EVA + RMS/MFR REPLACEMENT OF AFT EXTERNAL ORUS 2,4, 6–11

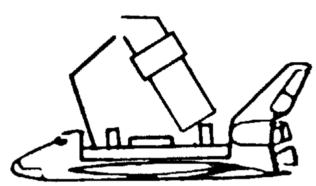
④



INSTRUMENT REPLACEMENTS

- AXAF AFT BULKHEAD REMOVED BY RMS, STOWED IN BAY
  - OMV
  - CARRIER
- EVA SEQUENTIAL REPLACEMENT OF AFT INTERNAL ORUS 1,3,5
- AXAF AFT BULKHEAD REPLACED BY RMS

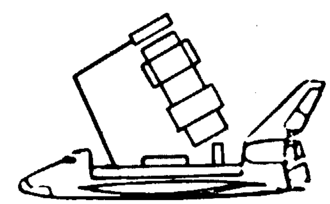
⑤



CONTINGENCY ASA OPNS

- RMS SNARES AFT GRAPPLE FIXTURE
- A' RELEASES AXAF
- RMS INVERTS AXAF, A' TO HORIZ. POSITION
- RMS BERTHS AXAF TO A', UMBILICAL CONNECT
- A' TILTS AXAF
- ASA CHANGEOUT SEQUENCE (Q.V.)

⑥



REDEPLOYMENT

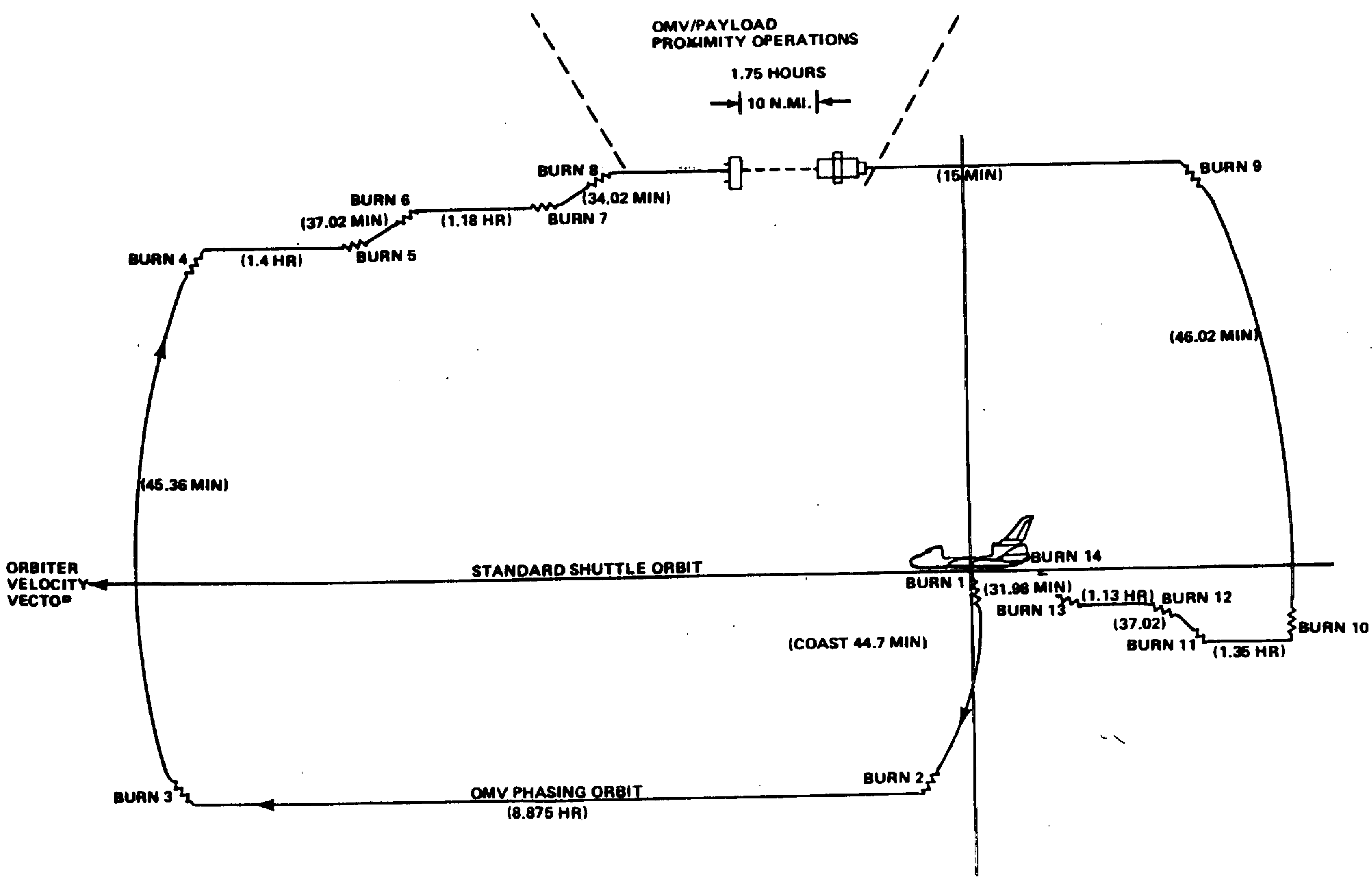
- RMS BERTHS OMV TO AXAF
- A' RELEASES AXAF
- RMS MOVES AXAF/OMV TO DEPLOYMENT POSITION

SELECTION FACTORS
PAYLOAD BAY MAINTENANCE LOCATIONS

	FORWARD	AFT
C.G/SHARING	–√ <u>REQUIRES</u> SHARED PAYLOAD SATISFYING BINDING LENGTH/C.G. CONSTRAINT	+ <u>ALLOWS</u> SHARED PAYLOAD WITH SOME CONSTRAINT
RMS REACH	– DOES NOT REACH ENTIRE AXAF, OMV ENVELOPE √– IMPLIES USE OF HPA <u>OR</u> MORE COMPLICATED PROXIMITY/HANDLING OPERATIONS <u>OR</u> SUBSTANTIAL MISSION – UNIQUE OMV REQUIREMENTS √– INCOMPATIBLE WITH AXIAL CHANGE-OUT OF ASPECT SENSOR ASSEMBLY	+ ENTIRE COMBINED ENVELOPE ACCESSIBLE BY RMS √+ PROVIDES EVA/MFR ACCESS TO ALL WORK AREAS + POTENTIAL FOR DIRECT OPERATIONS BETWEEN ORU CARRIER, SUBSYSTEMS RING o UTILIZES CRADLE A' TILT/ROTATE CAPABILITY
CONTINGENCY RETURN	–√ <u>REQUIRES</u> HPA TO ACCOMPLISH NECESSARY PAYLOAD BAY REPOSITIONING, COMPLEX OPERATIONS – MULTIPLE GRAPPLE POINTS REQUIRED ON AXAF, POSSIBLY ON OMV	+ STRAIGHTFORWARD REPOSITIONING OPERATIONS WITH RMS
AFD VIEWING DURING EVA OPS	o ALL WORK LOCATIONS VISIBLE FROM AFD	o DIRECT VIEWING OF ORU CARRIER – LOCATED OPERATIONS BLOCKED BY OMV; CCTV CAMERAS USED
PRECEDENTS	o NONE	+ SMRM, ST

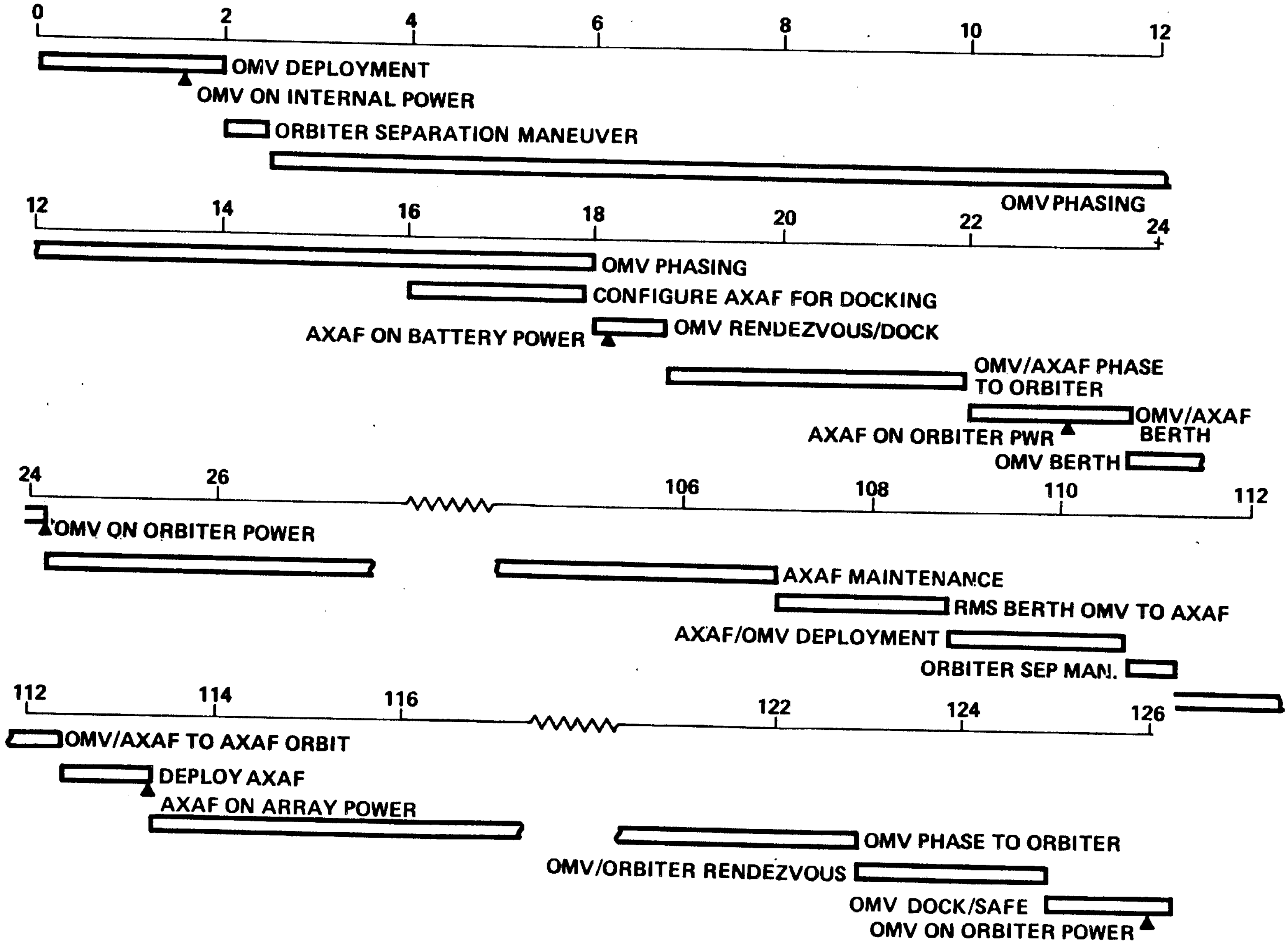
8707–83

OMV RETRIEVAL MISSION PROFILE (TYP.)



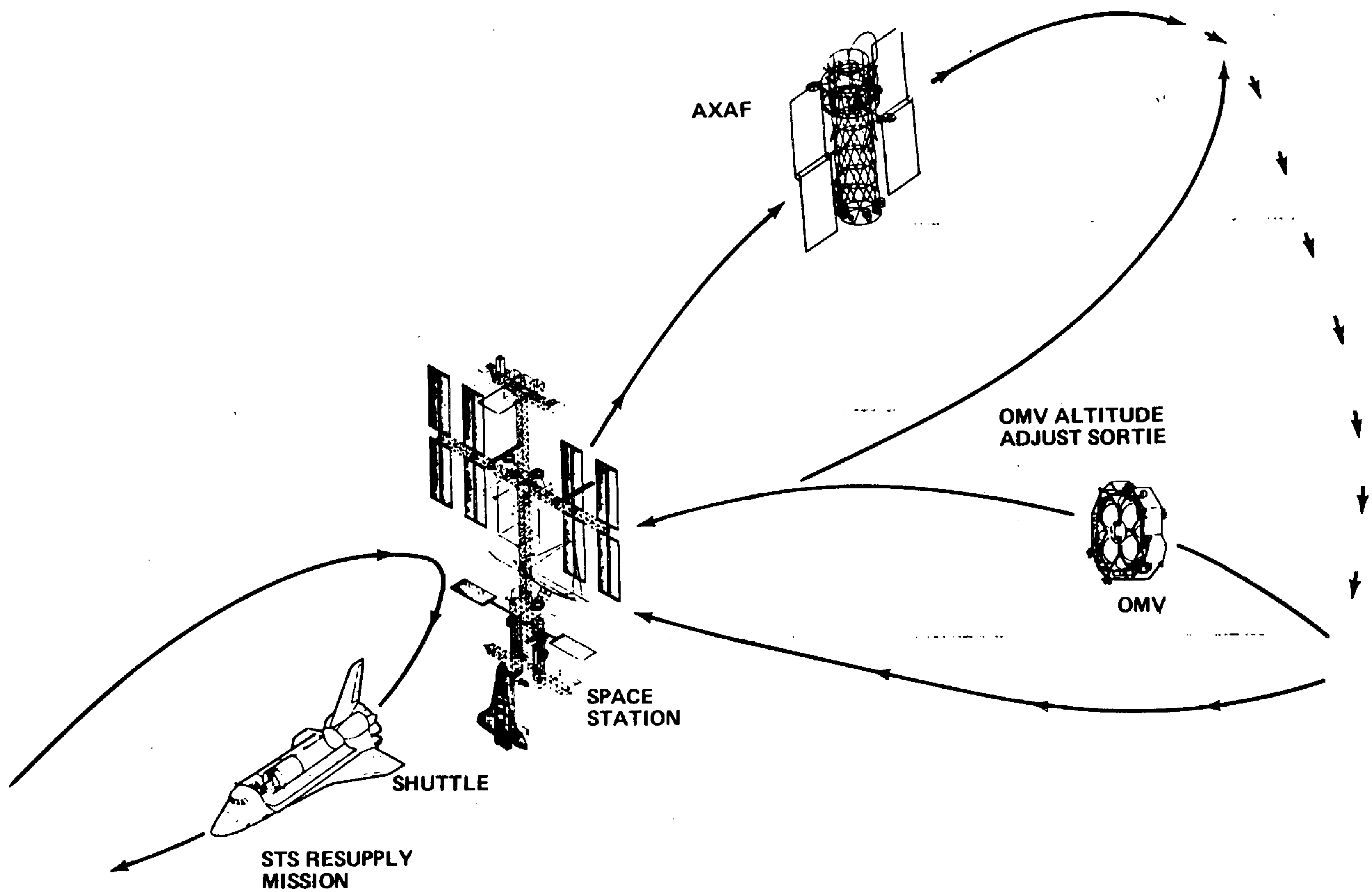
8995-83

AXAF/OMV MAINTENANCE MISSION
OPERATIONAL TIMELINE



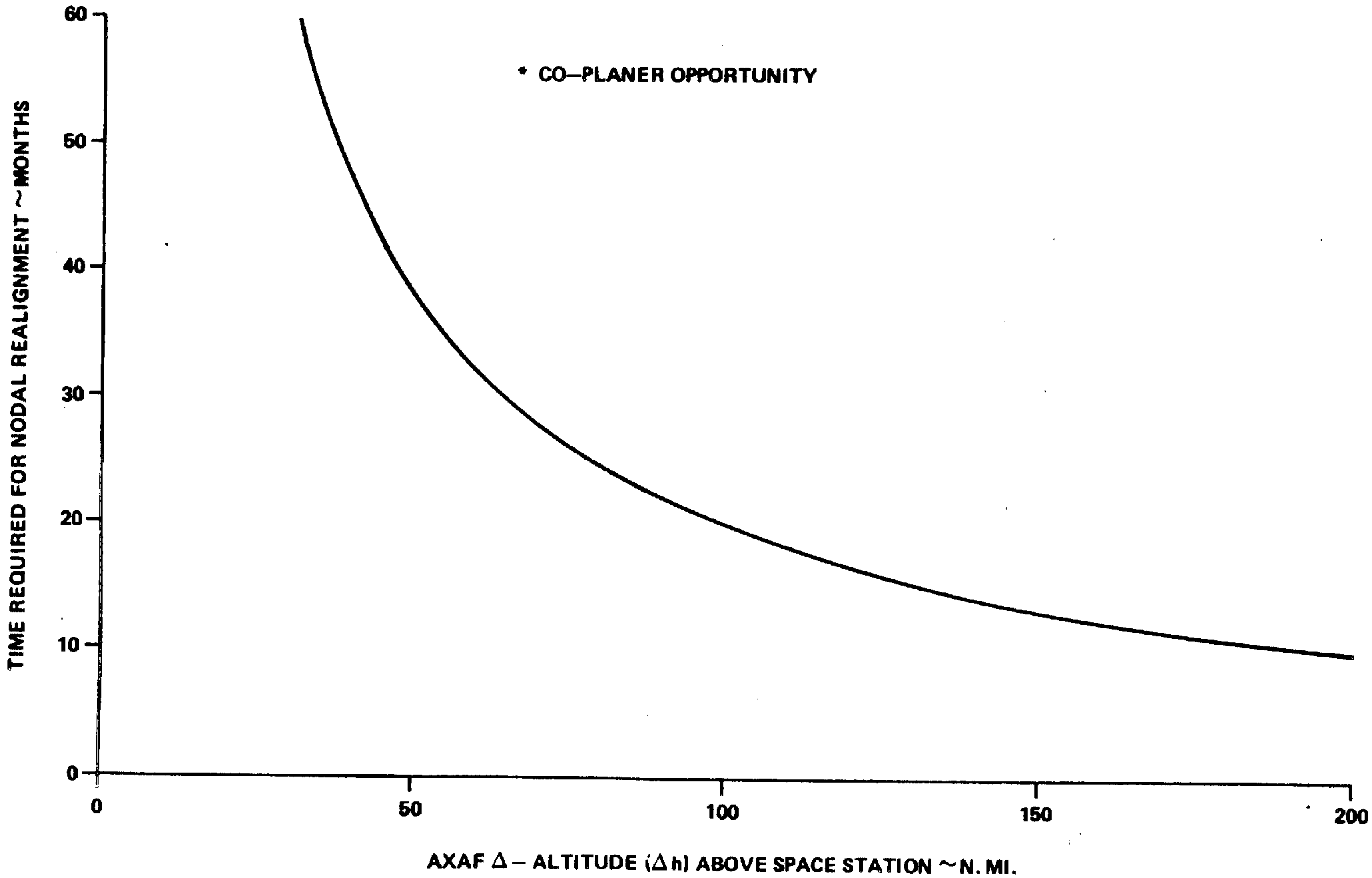
586–85

AXAF SPACE STATION-BASED OPERATIONS



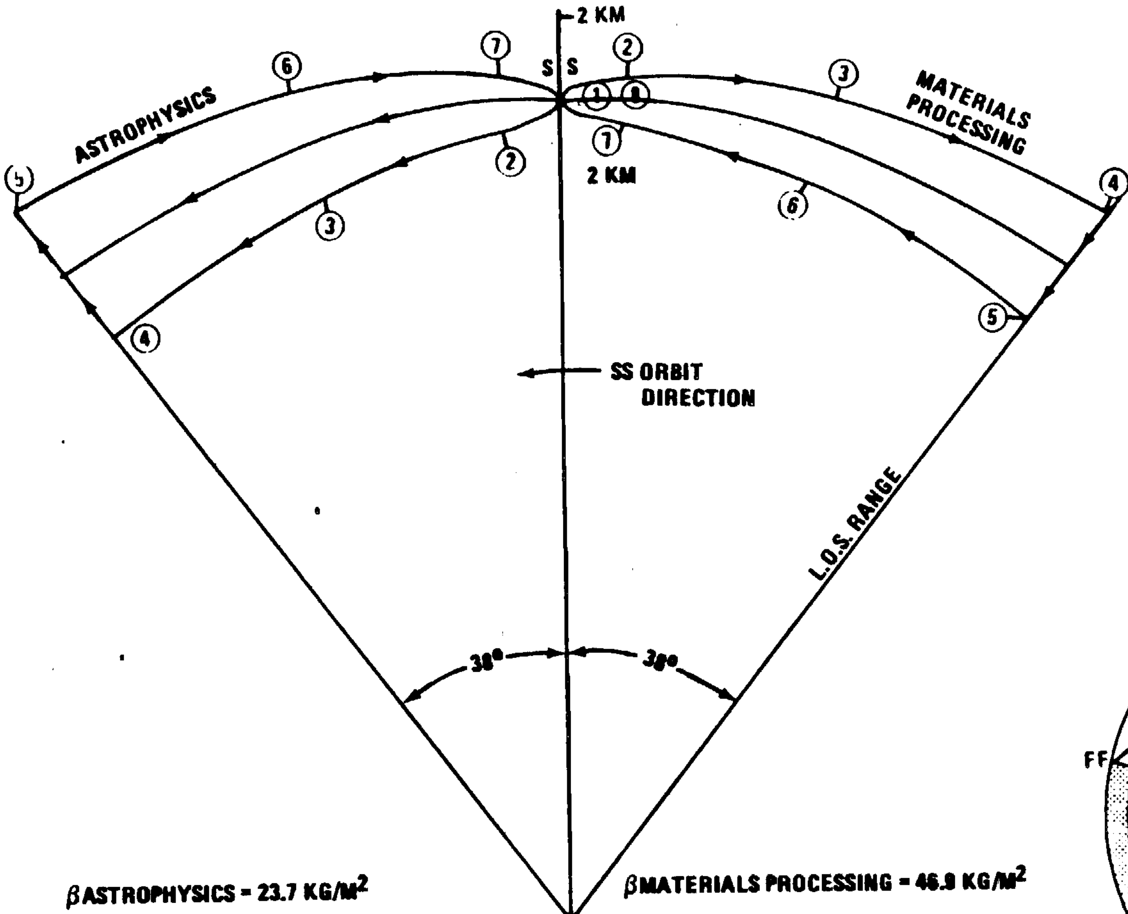
2858–82

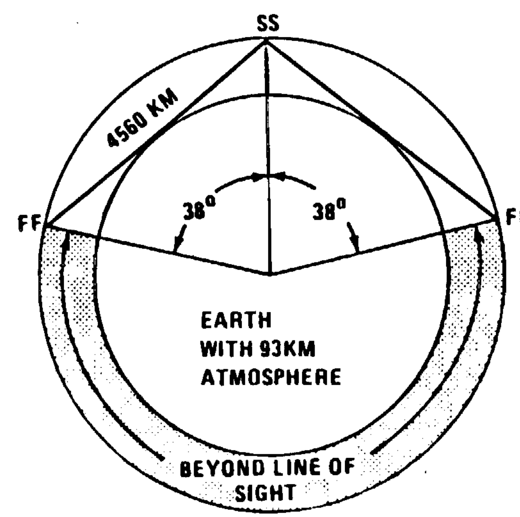
AXAF NODAL REALIGNMENT* AS A FUNCTION OF Δ - ALTITUDE ORBIT INCLINATION EQUAL 28.5 DEGREES



4944-82

SPACE STATION FORMATION FLYING/LINE OF SIGHT CONCEPT
SPACE STATION BALLISTIC COEFFICIENT (β STATION) = 33.5KG/M^2
SS INITIAL ALT = 250 N.MI., NOMINAL ATMOSPHERE DENSITY; 1992 LAUNCH DATE





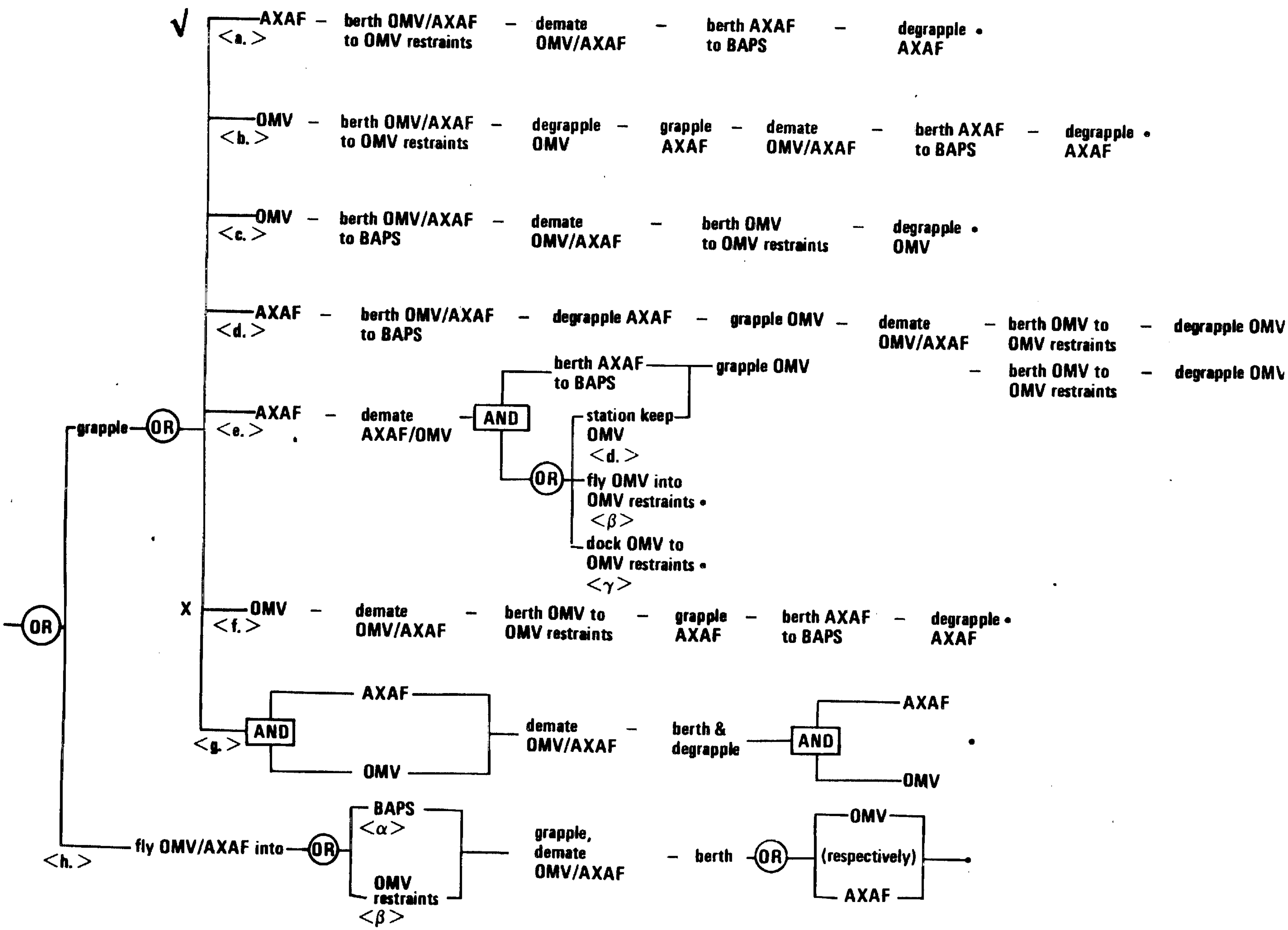
βASTROPHYSICS = 23.7 KG/M^2

POSITION	TIME (DAYS)	ANGLE (DEG)
1	0	0
2	10.00	4.6
3	20.00	18.4
4 REBOOST	28.70	38.0
6	38.15	18.4
7	48.15	4.6
8	58.15	0

βMATERIALS PROCESSING = 46.9 KG/M^2

POSITION	TIME (DAYS)	ANGLE (DEG)
1	0	0
2	12.00	−4.6
3	24.00	−18.4
4 DEBOOST	34.50	−38.0
6	45.75	−18.4
7	57.75	−4.6
8	69.75	0

5396–84



√
AXAF – berth OMV/AXAF to OMV restraints – demate OMV/AXAF – berth AXAF to BAPS – degrapple AXAF •
<a.>
OMV – berth OMV/AXAF to OMV restraints – degrapple OMV – grapple AXAF – demate OMV/AXAF – berth AXAF to BAPS – degrapple AXAF •
<b.>
OMV – berth OMV/AXAF to BAPS – demate OMV/AXAF – berth OMV to OMV restraints – degrapple OMV •
<c.>
AXAF – berth OMV/AXAF to BAPS – degrapple AXAF – grapple OMV – demate OMV/AXAF – berth OMV to OMV restraints – degrapple OMV
<d.>
grapple
OR
AXAF – demate AXAF/OMV – AND
<e.>
berth AXAF to BAPS
grapple OMV – berth OMV to OMV restraints – degrapple OMV
OR
station keep OMV
<d.>
fly OMV into OMV restraints •
<β>
dock OMV to OMV restraints •
<γ>
X
OMV – demate OMV/AXAF – berth OMV to OMV restraints – grapple AXAF – berth AXAF to BAPS – degrapple AXAF •
<f.>
OR
AND
<g.>
AXAF
OMV
demate OMV/AXAF – berth & degrapple
AND
AXAF
OMV
•
<h.>
fly OMV/AXAF into
OR
BAPS
<α>
OMV restraints
<β>
grapple, demate OMV/AXAF – berth
OR
OMV
(respectively)
AXAF

2-196

652–85

AXAF SERVICING MISSION CONCEPTS
— SUMMARY —

- SELECTED SHUTTLE—BASED MISSION CONCEPT MINIMIZES PROXIMITY OPERATIONS COMPLEXITY
  - ORBITER IS ACTIVE VEHICLE FOR FINAL CLOSURE TO GRAPPLE RANGE
  - TARGET (OMV/AXAF) ATTITUDE STABILIZATION CANDIDATES INCLUDE
    - GRAVITY GRADIENT
    - AXAF REACTION WHEELS
  - OMV RCS PROVIDES BACKUP/RECOVERY ATTITUDE STABILIZA–TION
- SPACE STATION—BASED PROXIMITY OPERATIONS CONCEPTS ARE BEING DEVELOPED

CONTAMINATION EFFECTS DURING RENDEZVOUS AND PROXIMITY OPERATIONS

E. MILLER/MSFC

J. ALRED/JSC

DEFINITIONS

- INDUCED CONTAMINATION -

  MOLECULAR GASES AND PARTICULATE MATERIALS ASSOCIATED WITH SPACECRAFT, PRODUCED BY SURFACE OFFGASSING, MATERIAL OUTGASSING, VENTING, DUMPING, ROCKET ENGINES, AND MECHANICAL SYSTEMS OPERATIONS WHICH RESULT IN PERFORMANCE DEGRADATION OF INSTRUMENTS AND/OR SPACECRAFT SYSTEMS.

- NUMBER COLUMN DENSITY (NCD) -

  THE NUMBER OF INDUCED CONTAMINANT MOLECULES IN A COLUMN OF UNIT AREA BETWEEN A SPACECRAFT BORNE SENSOR AND THE TARGET SOURCE.

- LIGHT CONTAMINATION -

  LIGHT PRODUCED DIRECTLY BY THE SPACECRAFT OR REFLECTED FROM NATURAL SOURCES THAT RESULTS IN PERFORMANCE DEGRADATION OF INSTRUMENTS AND/OR SPACECRAFT SYSTEMS.

INDUCED CONTAMINATION CONTROL LEVEL REQUIREMENTS FOR SHUTTLE AND SPACE STATION ARE UPPER LIMIT QUIESCENT OPERATION LEVELS, WHICH, IF EXCEEDED, MAY DEGRADE SCIENCE DATA AND POSSIBLY SPACECRAFT OPTICAL INSTRUMENTS, WINDOWS, AND THERMAL CONTROL SURFACES.

IT IS ANTICIPATED THAT THESE LEVELS WILL BE SIGNIFICANTLY EXCEEDED DURING RENDEZVOUS OPERATIONS.

INDUCED CONTAMINATION CONTROL LEVEL REQUIREMENTS FOR SHUTTLE/ SPACE STATION (DURING QUIESCENT OPERATIONAL PERIODS)

	SHUTTLE	SPACE STATION
• NCD -		
	$<10^{11}-10^{12}$, H_2O+CO_2	$<10^{11}$, H_2O+CO_2
	$<10^{13} cm^{-2}$, O_2+N_2	SAME
	$<10^{10} cm^{-2}$, OTHER GASES	SAME

EFFECTS - UV, IR OBSERVATIONS; SCATTERING, EMISSION, AND ABSORPTION.

	SHUTTLE	SPACE STATION
• MOLECULAR DEPOSITION -		
	$<10^{-5} g/cm^2$/30 DAYS/2π sr ON 300° K SURFACE	SAME
	$<10^{-7} g/cm^2$/30 DAYS/01. sr ON 300° K SURFACE	-
	$<10^{-5} g/cm^2$/30 DAYS/0.1 sr ON 20° K SURFACE	$1X10^{-11} g/cm^2/s$ ON 4^o K SURFACE

EFFECTS - OPTICAL SURFACES; SCATTERING, EMISSION, AND ABSORPTION.

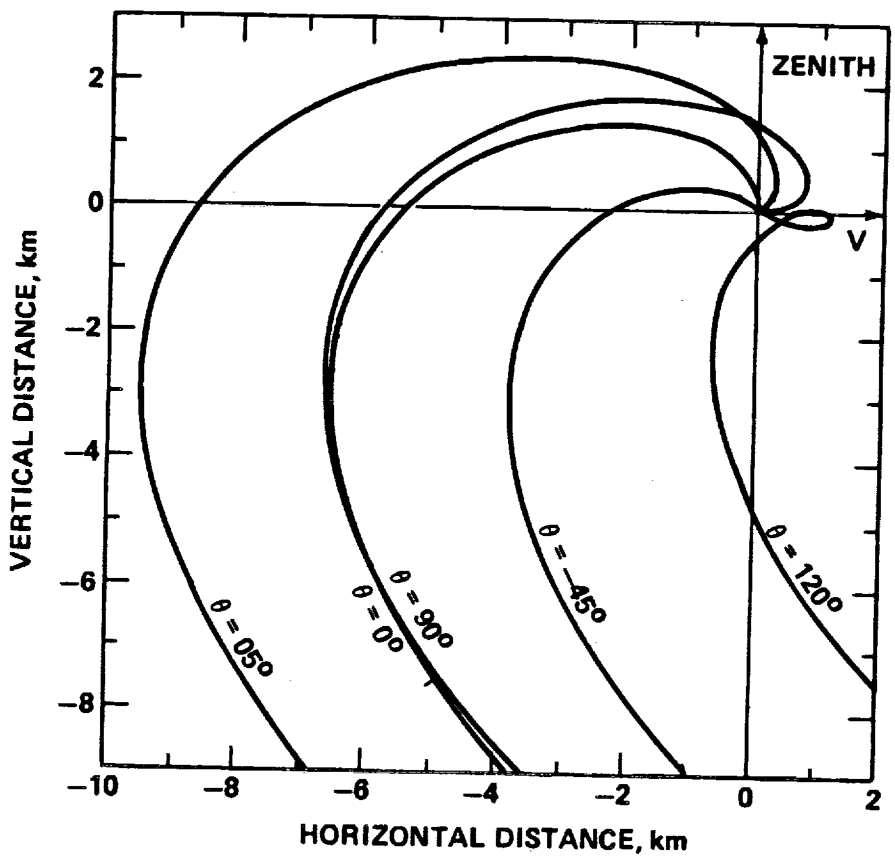
	SHUTTLE	SPACE STATION
• PARTICLE RELEASE		
	LESS THAN ONE DISCERNABLE ($\geq 5\mu m$ DIAMETER) PARTICLE PER ORBIT IN 0.25° FIELD-OF-VIEW	SAME

EFFECTS - UV, VISIBLE, IR OBSERVATIONS; SCATTERING AND EMISSION

SHUTTLE	SPACE STATION
• BRIGHTNESS BACKGROUND - PARTICULATE AND MOLECULAR SCATTERING AND EMISSION LESS THAN $10^{-14}B_{\odot}$ ($B_{\odot}$= SOLAR DISK BRIGHTNESS) IN ULTRA-VIOLET, $10^{-14.2}B_{\odot}$ IN VISIBLE SPECTRUM. INFRARED BACKGROUND $<10^{-11}$ WATTS/m^2/sr/nm FOR $\lambda<30$ m AND 10^{-10} WATTS/m^2/sr/nm FOR $\lambda>30\mu m$.	SHOULD NOT EXCEED NORMAL BACKGROUND SKY BRIGHTNESS OF NATURAL OCCURRING SOURCES.

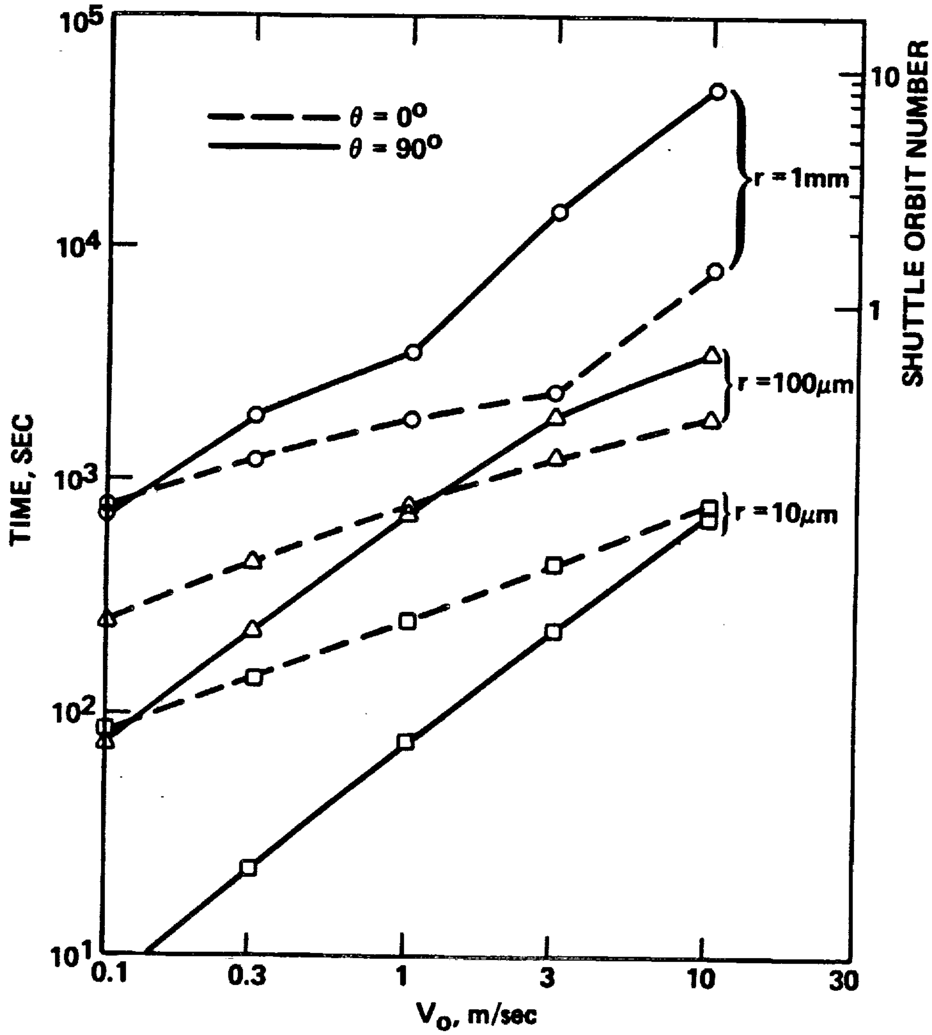
EFFECTS - UV, VISIBLE, IR OBSERVATIONS; DECREASE SIGNAL/NOISE

PARTICLES RELEASED FROM A SPACECRAFT LOSE ENERGY AND ORBIT DECAY DUE TO ATMOSPHERIC DRAG. THE LOCATION MOST LIKELY TO BE FREE OF LOW VELOCITY RELEASED PARTICLES IS $\gtrsim$ 1 km IN THE GENERAL VELOCITY VECTOR DIRECTION FROM THE RELEASING SOURCES.



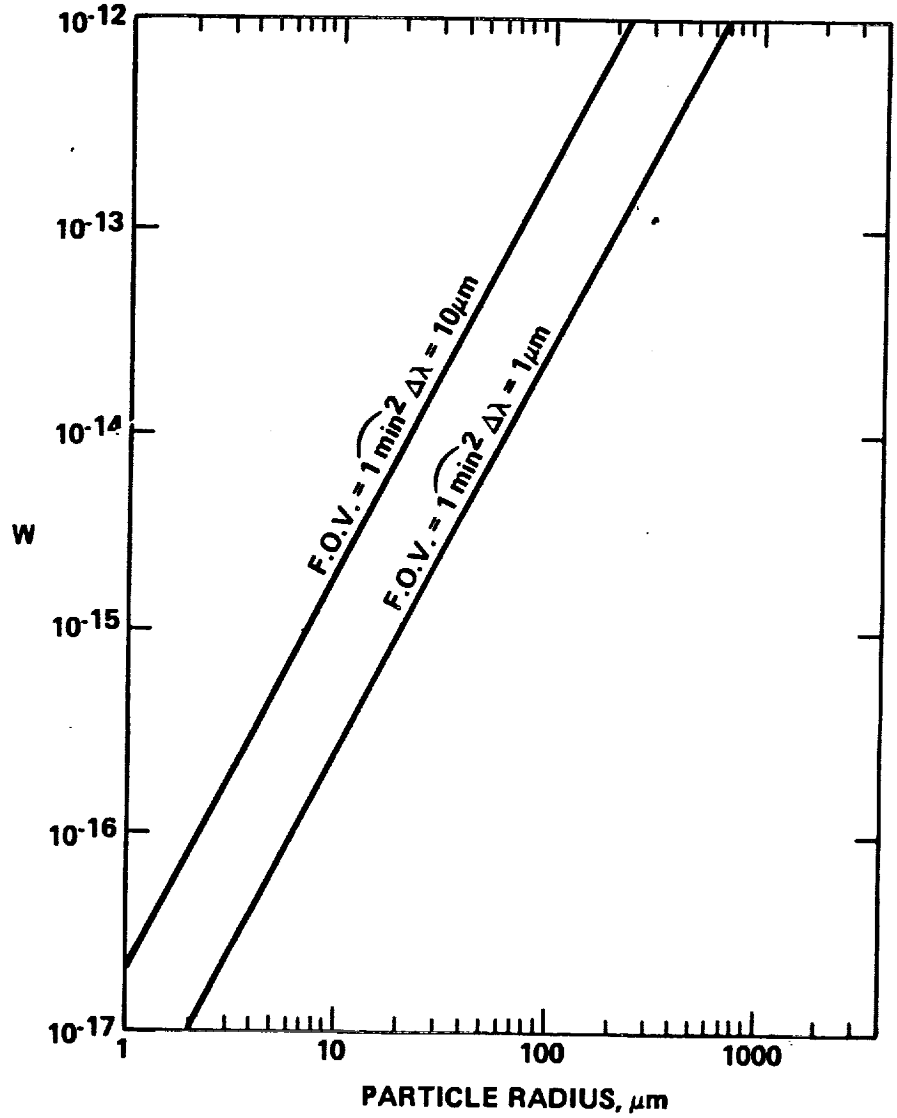
TRAJECTORIES AS VIEWED FROM THE SPACECRAFT ARE GIVEN FOR DUST PARTICLES WITH RADII = 100 μm AND INITIAL VELOCITIES OF 3 m/s AT 350 Km ALTITUDE. θ IS THE ANGLE FROM THE ZENITH OF THE INITIAL PARTICLE VELOCITY VECTOR V_0.

EFFECTIVE DECAY TIMES FOR PARTICLES RELEASED AT VARIOUS VELOCITIES.



THE TOTAL LENGTH OF TIME BEFORE THE PARTICLE PASSES BELOW THE SPACECRAFT ORBIT FOR THE LAST TIME IS GIVEN FOR EJECTION ANGLES $\theta = 0^o$ (STRAIGHT UP) AND $\theta = 90^o$ (IN THE DIRECTION OF THE VELOCITY VECTOR).

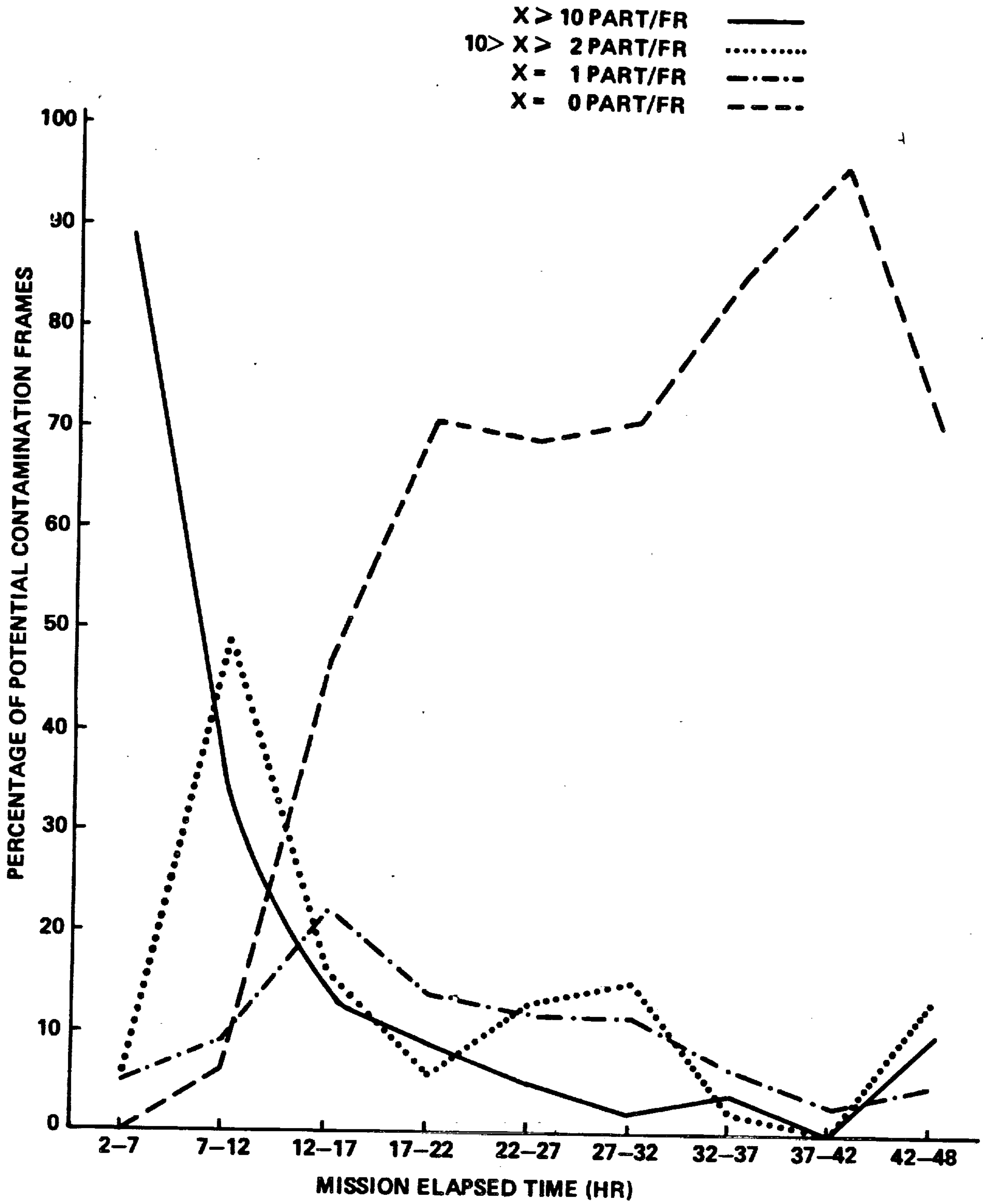
INFRARED RADIATION FROM SMALL PARTICLES ($\gtrsim$10 μm) CAN EXCEED CONTAMINATION CONTROL LEVEL REQUIREMENTS EVEN AT km DISTANCES. SUFFICIENT FREQUENCY OF THESE EVENTS (>1 PER ORBIT) BEGIN TO DEGRADE SCIENCE DATA FROM WEAK TARGET SOURCES.



THE POWER RADIATED ONTO THE DETECTOR OF A 1-m TELESCOPE AT λ = 10μm IS GIVEN AS A FUNCTION OF PARTICLE RADIUS FOR A 300K DUST PARTICLE WITH UNIT EMISSIVITY. THE BANDWIDTHS $\Delta\lambda$ ARE 10μm AND 1μm. PARTICLE DISTANCE $\lesssim$ 2.5 Km.

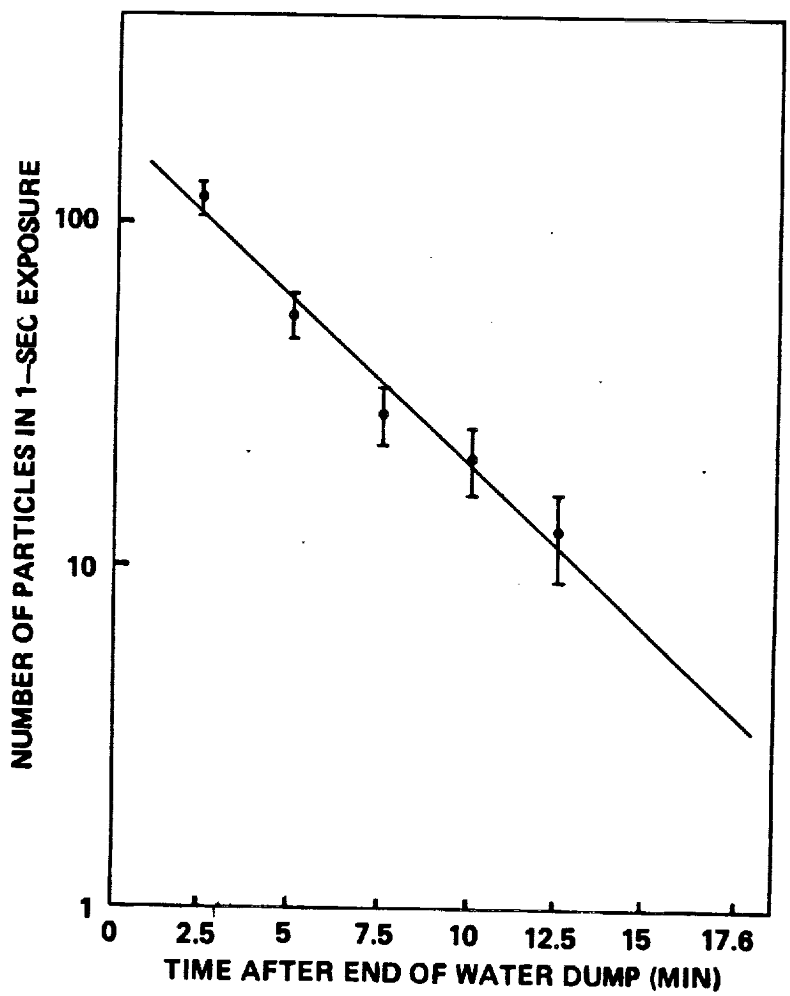
DATA OBTAINED BY THE INDUCED ENVIRONMENT CONTAMINATION MONITOR (IECM) ON EARLY SHUTTLE FLIGHTS SHOW PARTICLE RELEASE EVENTS DECREASE TO A MUCH LOWER, SOMEWHAT STEADY LEVEL AFTER ABOUT 15 HOURS MISSION ELAPSE TIME. THE IECM DATA FROM STS-9 (SPACELAB 1) INDICATE A SIMILAR EARLY DECREASE IN PARTICLE CONCENTRATION, BUT WITH SUBSEQUENT PEAKS.

IN ADDITION TO THE PARTICLES SEEN DURING MOSTLY QUIESCENT OPERATION PERIODS, WATER DUMPS PRODUCED HEAVY CONCENTRATIONS THAT HAVE BEEN DESCRIBED AS SNOW STORMS.



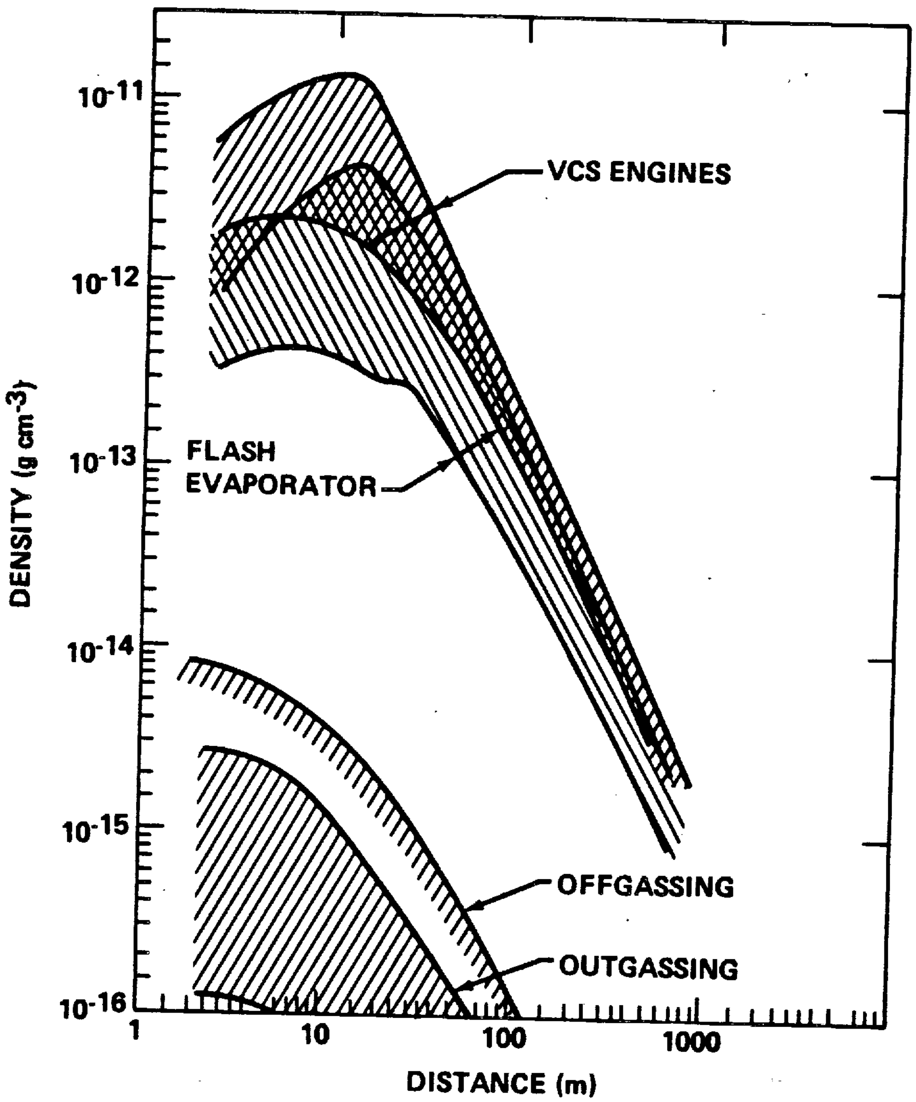
A summary of the contamination observed during the first 48 hr combined from the STS-2, -3, and -4 missions. Curves are presented showing the time histories of particle concentrations (particles/frames) recorded by the cameras. Heavier concentrations of particles are recorded very early in the mission, with fewer particles being recorded as the mission progresses.

HEAVY CONCENTRATION OF PARTICLES IN THE VICINITY OF THE SHUTTLE BAY ARE SEEN DURING WATER DUMPS WHICH TYPICALLY LAST FOR ABOUT 1 HOUR. PARTICLE CONCENTRATION DECAY, UPON TERMINATION OF DUMPS, WAS DETERMINED BY THE IECM ON STS-4 (300 km ALTITUDE) TO HAVE A TIME CONSTANT (1/e) OF ABOUT 5 MINUTES.



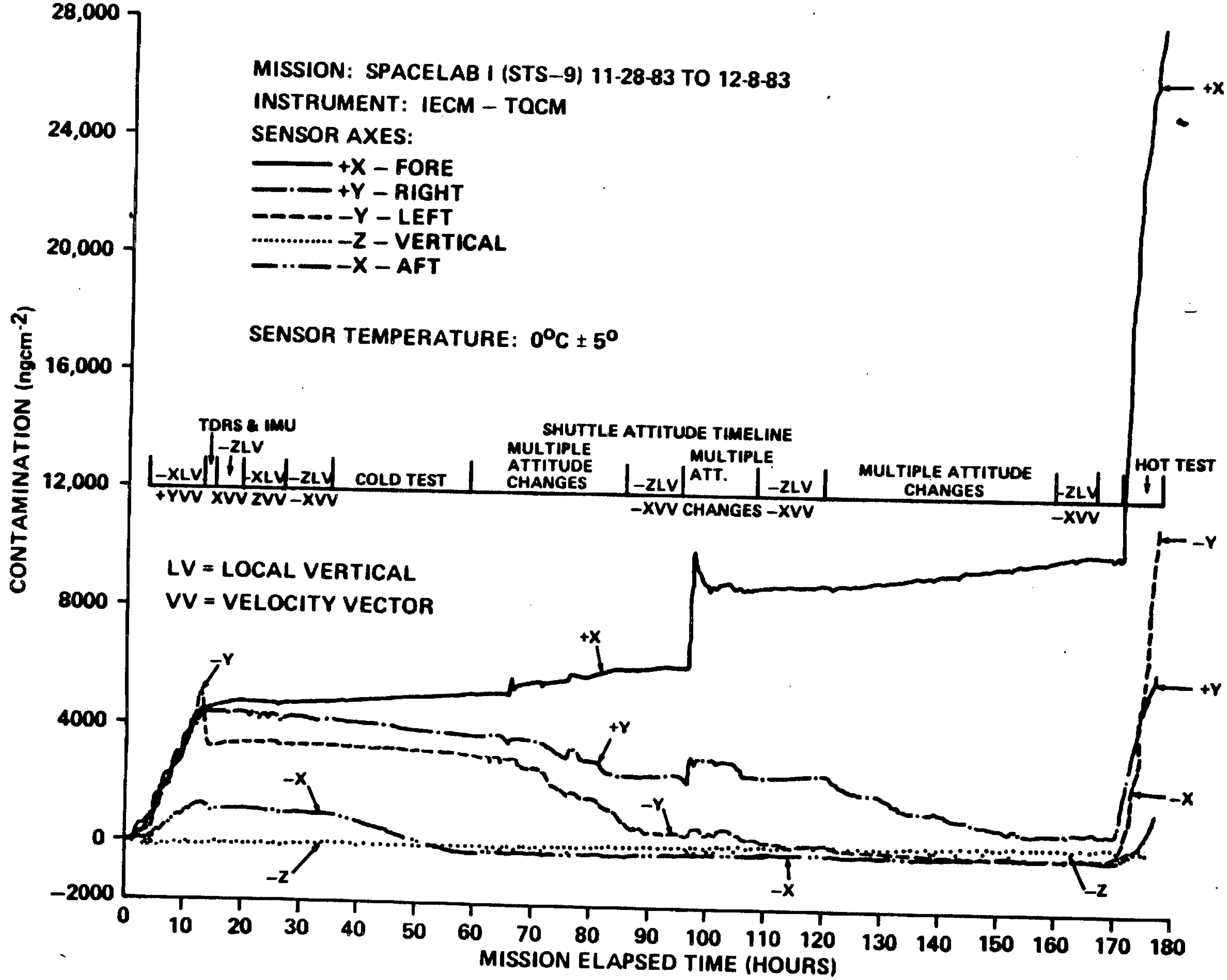
PARTICLE COUNT DECAY AFTER WATER DUMP TERMINATION.

INDUCED SPACECRAFT MOLECULAR CONTAMINATION IS PRODUCED BY EARLY OFFGASSING OF ADSORBED MATERIALS ON SURFACES, OUTGASSING OF MATERIALS, VENTINGS, DUMPS, ENGINE FIRINGS, ETC. THE DENSITIES PRODUCED CAN BE PREDICTED AT VARIOUS DISTANCES FROM A SPACECRAFT AND SHOW THE COMPARATIVE MAGNITUDES OF THESE SOURCES.



MOLECULAR DENSITY VERSUS DISTANCE AT 400 Km ORBIT

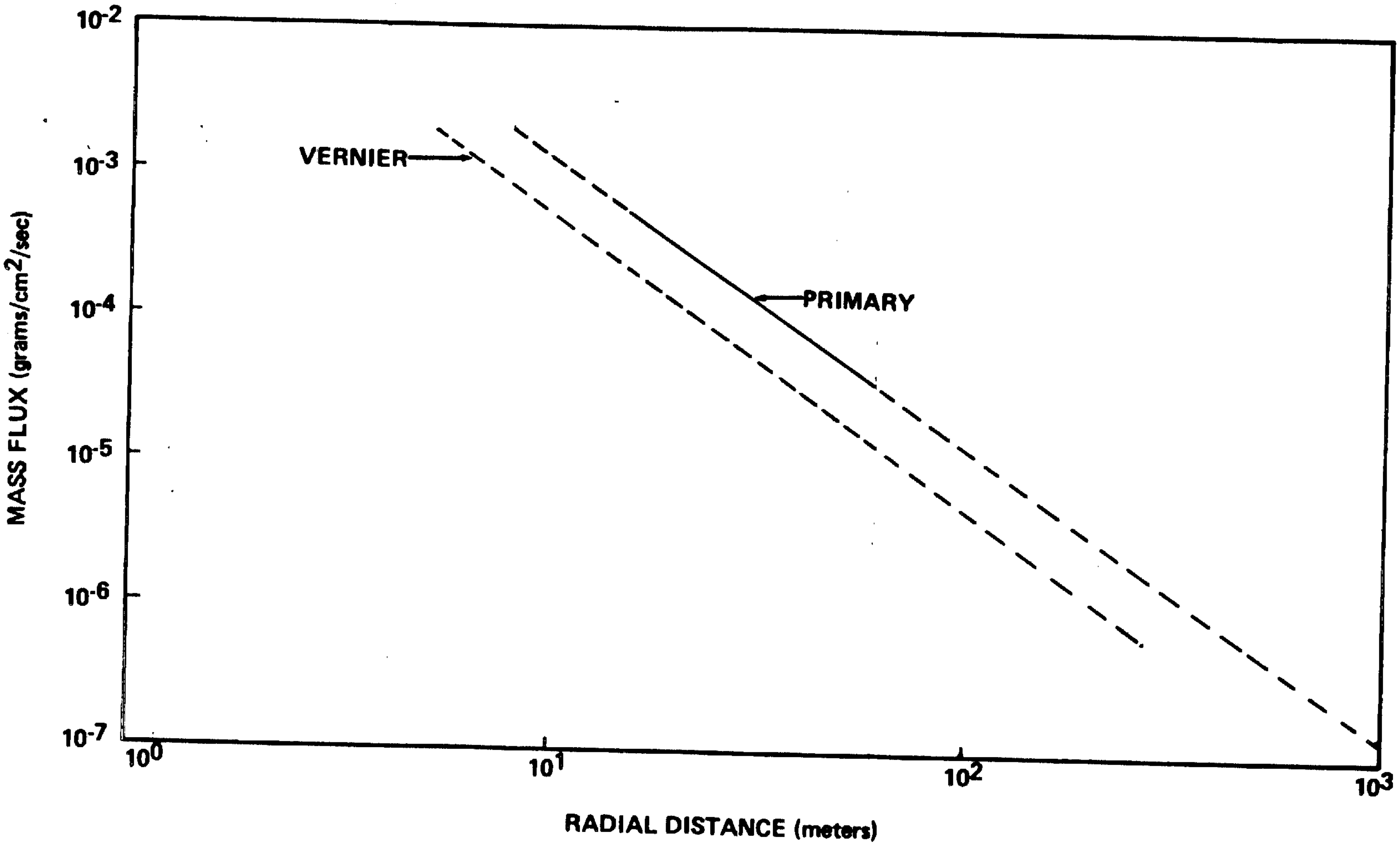
MOLECULAR DEPOSITION ON SPACECRAFT SURFACES OCCURS BOTH BY LINE-OF-SIGHT AND BY RETURN FLUX, CAUSED BY COLLISIONAL SCATTERING WITH ATMOSPHERIC MOLECULES. THE RELATIVE EFFICIENCY OF THESE TRANSPORT MECHANISMS CAN BE SEEN BY COMPARING THE CONTAMINATION OF $\pm X$ AND $\pm Y$ IECM SENSORS, WHICH HAD DIRECT VIEWING TO THE SPACE-CRAFT AND PALLET INSTRUMENTS, TO THE SPACE VIEWING-Z SENSOR. EARLY MISSION OFFGASSING AND OUTGASSING EFFECTS ARE EASILY SEEN ON THE DIRECT VIEWING SENSORS AS ARE PERIODS OF HIGH HEAT LOADS AT ~97 HOURS AND ~/70 HOURS. RENDEZVOUSING VEHICLES WOULD BE SUBJECT TO LINE-OF-SIGHT DEPOSITIONS.



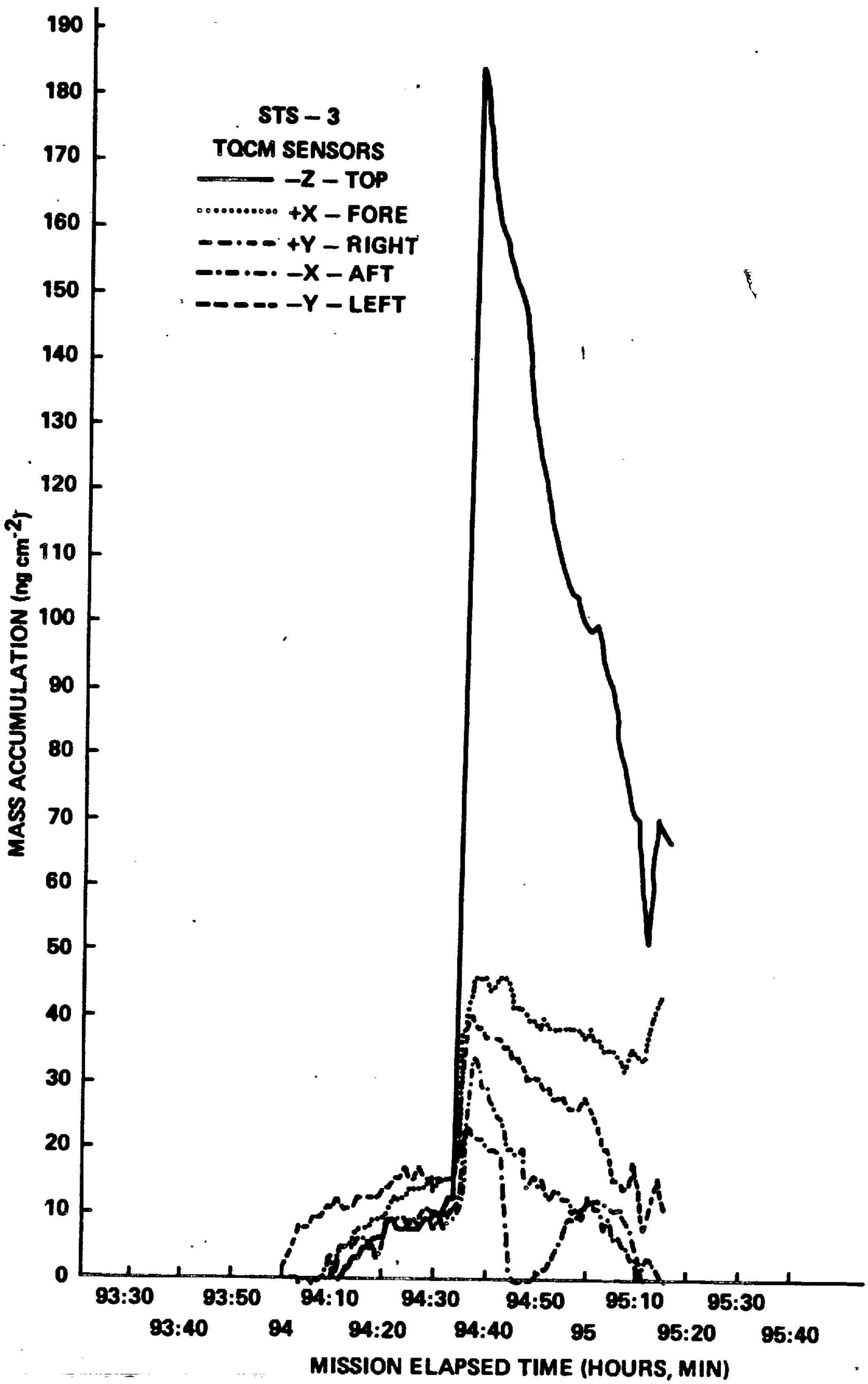
Surface contamination as measured by TQCM on Spacelab 1.

PLUME IMPINGEMENT FROM A PRIMARY RCS THRUSTER WAS MEASURED ON STS-7 UTILIZING THE SPAS-01 SPACECRAFT. THE RESULTS OF THESE MEASUREMENTS (SOLID LINE) VALIDATED THE SOURCE FLOW IMPINGEMENT MODEL DATA (DASHED LINES). THE SMALL DIFFERENCE IN MASS FLUX BETWEEN THE RCS AND VRCS ALONG THE CENTERLINE OF THESE ENGINES IS DUE TO MASS FROM THE VRCS BEING EJECTED INTO A SMALLER CONE (LESS SPREADING).

MASS FLUX OF PRIMARY/VERNIER RCS JET



ENGINE PRODUCT DEPOSITIONS EVEN FROM RETURN FLUX CAN BE SIGNIFICANT. THE DEPOSITIONS SHOWN HERE ARE ON A 30°C SURFACE AND TEND TO DISSIPATE IN TENS OF MINUTES. AT COLDER TEMPERATURES THE DISSIPATION WOULD BE SLOWER.



Mass accumulation during STS-3 L2U engine firing.

LIGHT CONTAMINATION EXISTS FROM NATURAL AND SPACECRAFT SOURCES. BRIGHTNESS VALUES GIVEN HERE OFFER A COMPARISON OF THE PHOTOMETRIC VALUES OF SEVERAL SOURCES. LIGHT PRODUCED BY THRUSTERS EXTENDS INTO THE NEAR INFRARED AND SURFACE GLOW PEAKS IN THE RED SPECTRAL REGION AND MAY EXTEND INTO THE NEAR INFRARED.

LIGHT SOURCES AND BRIGHTNESS COMPARISONS

SOURCE	BRIGHTNESS*	RATIO TO SOLAR DISK BRIGHTNESS, $B_{\odot}$	NOTES
SUN	2×10^{15}	1	AVERAGE SOLAR DISK BRIGHTNESS
MOON	4×10^{9}	2×10^{-6}	
ZODIACAL LIGHT	50-2200	2.5×10^{-14} - 1.1×10^{-12}	NEAR ECLIPTIC POLES TO 30° FROM SUN IN THE ECLIPTIC PLANE
BACKGROUND STARLIGHT	30-1000	1.5×10^{-14} - 5×10^{-13}	
SHUTTLE VCS ENGINES	400-2600	2×10^{-13} - 1.3×10^{-12}	MEASURED INDIRECTLY (IN-BAY) BY SHUTTLE INDUCED ATMOSPHERE (SIA) PHOTOMETER ON STS-3
GLOW ASSOCIATED WITH SATELLITE SURFACES	UP TO ~2000	1×10^{-12}	ESTIMATED FROM STS-3 FLIGHT DATA. BRIGHTNESS IS ALTITUDE DEPENDENT (BRIGHTER AT LOWER ALTITUDES).

*IN UNITS OF EQUIVALENT NUMBER OF 10TH MAGNITUDE SOLAR TYPE STARS PER SQUARE DEGREE, [$S_{10}(V)$] (VISIBLE THRESHOLD ≈200).

CONTAMINATION AVOIDANCE

RENDEZVOUS

- USE APPROACH TECHNIQUES THAT MINIMIZES THRUSTER FIRINGS, ESPECIALLY IN THE DIRECTION OF VEHICLES.
- INHIBIT (OR MINIMIZE) DUMPS, EVAPORATOR AND VENTING OPERATIONS.
- MAINTAIN ATTITUDES THAT MINIMIZE THRUSTER FIRINGS.

PROXIMITY OPERATIONS:

- MAINTAIN SEPARATION DISTANCES OF GREATER THAN 1 km. KEEP THE CLEANER VEHICLE (OR THE VEHICLE WITH THE MORE STRINGENT REQUIREMENTS) IN FRONT.

MAJOR CONCERNS

- CRYOGENIC SURFACES ($<140^{o}K$) ARE MOST SUSCEPTABLE TO CONTAMINATION AND THEREFORE REQUIRE MORE PROTECTIVE/AVOIDANCE MEASURES.
- LONG TERM (MONTHS FOR SCIENCE AND TECHNOLOGY EXPERIMENTS, YEARS FOR SPACECRAFT SYSTEMS AND SUBSYSTEMS) NATURAL AND INDUCED ENVIRONMENT EFFECTS THAT MAY BE SYNERGISTIC AND/OR ACCUMULATIVE.

REFERENCES

CHARTS, 1, 2 - SPACE SHUTTLE SYSTEM PAYLOAD ACCOMMODATIONS, LEVEL II PROGRAM DEFINITION AND REQUIREMENTS, VOL. XIV, JSC 07700

- SPACE STATION PROGRAM DESCRIPTION DOCUMENT, NASA TM-86652, MARCH 1984.

CHART 3, 4, 5, - EFFECT OF SHUTTLE CONTAMINANT ENVIRONMENT ON A SENSITIVE INFRARED TELESCOPE, J. P. SIMPSON AND F. C. WITTEBORN, JOURNAL OF APPLIED OPTICS, VOL. 16, NO. 8, PP. 2051-2073, AUG. 1977.

CHART 6 -STS-2, -3, -4, - INDUCED ENVIRONMENT CONTAMINATION MONITOR (IECM) SUMMARY REPORT, EDITED BY E. R. MILLER, NASA TM-82524, FEB. 1983.

CHART 7 - UPDATE OF INDUCED ENVIRONMENT CONTAMINATION MONITOR RESULTS. E. R. MILLER, AIAA 83-2582-CP, PRESENTED AT AIAA SHUTTLE ENVIRONMENTS AND OPERATIONS MEETING, WASHINGTON, D. C., OCT.31 - NOV. 2 1983.

CHART 8 - ASSESSMENT OF SHUTTLE PAYLOADS GASEOUS ENVIRONMENT CONTAMINATION AND ITS CONTROL, J. J. SCIALDONE, ESA SP-145, DEC. 1979.

CHART 9 - INDUCED ENVIRONMENT CONTAMINATION MONITOR - PRELIMINARY RESULTS FROM SPACELAB 1 FLIGHT, EDITED BY E. R. MILLER, NASA TM-86461, AUG. 1984.

CHART 10 - RESULTS OF THE SPAS-01 RCS PLUME IMPINGEMENT TEST, M. P. LAZARON AND J. W. ALRED, PRESENTED AT THE AIAA 23rd AEROSPACE SCIENCES MEETING, RENO, NEVADA, JAN. 14-17, 1985.

CHART 11 - SEE CHART 6.

CHART 12 - THE SHUTTLE OPTICAL ENVIRONMENT: LOCAL AND ASTRONOMICAL, J. L. WEINBERG, PRESENTED AT AIAA SHUTTLE ENVIRONMENTS AND OPERATIONS MEETING, WASHINGTON, D. C., OCT. 31 - NOV. 2, 1983.

- OBSERVATIONS OF OPTICAL EMISSIONS ON STS-4, S. B. MENDE, O. K. GARRIOT, P. M. BANKS, GEOPHYSICAL RESEARCH LETTERS, VOL. 10, NO. 2, PP 122-125, FEB. 1983.

SESSION 3 - PLANNED SYSTEMS CAPABILITIES PLENARY SESSION

3-1. "STS-BASED SERVICES" - ALLEN LOUVIERE/NASA JSC

3-2. "TETHERED SATELLITE SYSTEM PROXIMITY OPERATIONS" - A. LORENZONI/PSN/CNR AND C. RUPP/NASA MSFC

3-3. "OMV: THE KEY TO SATELLITE SERVICING" - ART STEPHENSON/ TRW

3-4. "OMV SERVICING CAPABILITY" - FRANK BERGONZ/MMA

3-5. "THE ORBITAL MANEUVERING VEHICLE" - R. FRENCY/LTV

3-6. "ORBITAL TRANSFER VEHICLE (OTV)" - R. E. AUSTIN AND D. R. SAXTON/NASA MSFC

3-7. "FUTURE SPACE AND GROUND NETWORK CAPABILITES" - JAMES COOLEY/NASA GSFC

STS-BASED SERVICES

ALLEN J. LOUVIERE

NASA LYNDON B. JOHNSON SPACE CENTER

RENDEZVOUS AND PROXIMITY OPERATIONS WORKSHOP

20 FEBRUARY 1985

CATEGORIES OF ON-ORBIT SERVICES

- STS/ORBITER PROVIDES THREE BASIC CATEGORIES OF ON-ORBIT SERVICES, ASSOCIATED WITH RENDEZVOUS AND PROXIMITY OPERATIONS:
  - DELTA-V TRANSFERS FOR TRANSPORTATION
  - PAYLOAD DEPLOYMENT AND RETRIEVAL
  - SATELLITE SERVICING

- SERVICES CAN CONSIST OF:
  - ORBITER MANUEVERS
  - REMOTE MANIPULATOR SYSTEM OPERATIONS
  - EXTRAVEHICULAR ACTIVITIES (CREWMAN WITH EXTRAVEHICULAR MOBILITY UINT IN P/L BAY AREA OR IN CONJUNCTION WITH RMS - NO MANNED MANEUVERING UNIT)
  - MANNED MANEUVERING UNIT (MMU) OPERATIONS

TRANSPORTATION SERVICES

(SEE ATTACHED SUMMARY)

- DELIVERY AND RETURN OF ATTACHED PAYLOADS TO LOW-EARTH ORBIT (LEO)
- DIRECT DELIVERY AND RELEASE OF DETACHED PAYLOADS IN LEO
- TRANSFER PAYLOAD AND UPPER STAGE TO STAGING ORBIT

MISSION	CHARGEABLE P/L WT AT LIFTOFF	DEPLOYED P/L WEIGHT	RETURNED P/L WEIGHT	DEPLOYABLE PAYLOADS	ATTACHED PAYLOADS
STS-5	20,830	14,585	6,245	• SBS-C/PAM-D • ANIK-C/PAM-D	• DEVELOPMENT FLIGHT INST. (DFI)
STS-6	46,662	37,546	9,116	• TDRS-A/IUS	• CARGO BAY STOWAGE ASSEMBLY (CBSA)
STS-7	31,893	14,949	16,944	• ANIK-C/PAM-D • PALAPA-B1/PAM-D	• OSTA-2 • CBSA
STS-8	25,790	7,445	18,345	• INSAT/PAM-D • PAYLOAD FLIGHT TEST ARTICLE (PFTA)	• DFI • CBSA • SPAS-01
STS-9	33,131	0	33,131	NONE	• SPACELAB-1 • EXPERIMENTS (73)
STS 41-B	28,252	14,863	13,389	• WESTAR VI/PAM-D • PALAPA-B/PAM-D • SPAS-01 (NOT DEPLOYED) • INTEGRATED RENDEZVOUS TARGET)	• MANIPULATOR FOOT RESTRAINT • SPECIAL EQUIPMENT STOWAGE • CINEMA 360
STS 41-C	33,831	21,396	12,435	• LDEF • SMM SPACECRAFT	• SMRM - FLIGHT SUPPORT SYSTEM • CINEMA 360 • CBSA
STS 41-D	41,382	30,086	11,296	• SBS/PAM-D • SYNCOM IV-2 • TELSTAR/PAM-D	• OAST-1
STS 41-G	18,059	5,087	12,972	• EARTH RADIATION BUDGET SATELLITE (ERBS)	• OSTA-3 • LARGE FORMAT CAMERA • ORBITAL REFUELING SYSTEM
STS 51-A	38,003	22,764	17,559	• TELESAT-H (ANIK)-D2/ PAM-D • SYNCOM IV-1	• PALAPA-B2 (RETRIEVED) • WESTAR-VI

PAYLOAD DEPLOYMENT AND RETRIEVAL

- FOUR MODES OF DETACHED PAYLOAD DEPLOYMENT:
  - SPIN-UP, SPRING-RELEASE - PAM-D SERIES
  - TILT-UP, SPRING RELEASE - IUS SERIES
  - "FRISBEE" TOSS - SYNCOM IV-1 AND SYNCOM IV-2
  - RMS DEPLOYMENT (CAPABILITIES: DEPLOY AND RETRIEVE - 32K LBS; DEPLOY ONLY - 64K LBS)

SUMMARY OF RMS OPERATIONS

MISSION	PAYLOAD	WEIGHT	RMS OPERATION
STS-2	NONE	N/A	UNLOADED ARM TESTS
STS-3	PLASMA DIAGNOSTIC PACKAGE	343.5	ATTACHED UNBERTHING/REBERTHING
STS-4	IECM	816.2	ATTACHED UNBERTHING/REBERTHING
STS-7	SPAS-01	3,968.3	UNBERTHING/DEPLOY/BERTHING TESTS
STS-8	P/L FLIGHT TEST ARTICLE	7,460.0	ATTACHED UNBERTHING/BERTHING
STS 41-B	SPAS-01	3,968.3	NOT DEPLOYED DUE TO RMS ANOMALY
STS 41-C	LDEF	21,528.0	DEPLOYED
	SOLAR MAXIMUM	4,500.	RDZ/RETRIEVE/REPAIR/DEPLOY
STS 41-D	OAST-1	673.9	ATTACHED OPERATIONS
STS 41-G	ERBS	5,400.	DEPLOYMENT
STS 51-A	PALAPA	1,262.	RETRIEVE (2,092 LBS WITH MMU/ETC.)
	WESTAR	1,262.	RETRIEVE (2,092 LBS WITH MMU/ETC.)
STS 61-J	SPACE TELESCOPE	23,786.5	DEPLOY

SUMMARY OF EVA OPERATIONS

MISSION	CREW NO.	EVA's	USE OF MMU?	EVA OPERATIONS
STS-7	2	1	NO	PAYLOAD BAY OPERATIONS
STS 41-B	2	3	YES	PAYLOAD BAY OPERATIONS, EMU FLIGHT TEST
STS 41-C	2	3	YES	PAYLOAD BAY OPERATIONS, SMM RETRIEVE AND REPAIR
STS 41-G	2	1	NO	PAYLOAD BAY OPS/ORS OPERATIONS
STS 51-A	2	3	YES	PALAPA/WESTAR RETRIEVALS, PAYLOAD BAY OPERATIONS

MAN'S ABILITY TO WORK IN ZERO-G AND OUTSIDE THE ORBITER

- BEGAN WITH SIGNIFICANT UNKNOWNS REGARDING MAN'S PHYSICAL CAPABILITIES IN EVA ENVIRONMENT
  - CREW MOBILITY, STRENGTH, AND DEXTERITY
  - TOOLS FOR ZERO-G AND SPACE-SUITED OPERATIONS

- HIGH EMPHASIS ON CREW TRAINING IN WEIGHTLESS ENVIRONMENT TEST FACILITY (AVAILABLE ON THURSDAY AFTERNOON TOURS) AND MMU SIMULATIONS.

- ACTUAL MANNED PERFORMANCE ON SOLAR MAXIMUM REPAIR, PALAPA/WESTAR RESCUES, AND ORBIT REFUELING SYSTEM OPERATIONS WERE EXCELLENT
  - DEMONSTRATED CAPABILITY AND ADAPATABILITY OF MAN IN EVAs
  - PROVED VALUE OF WETF AND MMU SIMULATION

SATELLITE SERVICING

- SYSTEMATIC DEVELOPMENT OF STANDARD SATELLITE SERVICES
  - NASA INTERCENTER MEETINGS
  - WORKSHOPS:
    - 2-DAYS IN 1982 - "SATELLITE SERVICES CATALOG - TOOLS AND EQUIPMENT"
    - POTENTIAL WORKSHOP IN MAY 1985
  - CONTRACTED STUDIES:
    - SATELLITE SERVICE HANDBOOK - INTERFACE GUIDELINES
- DEMONSTRATIONS OF ON-ORBIT SERVICES
  - SOLAR MAXIMUM REPAIR MISSION
  - ORBITAL REFUELING SYSTEM OPERATIONS
  - PALAPA/WESTAR RETRIEVALS
- NASA POLICY STATEMENT: ALL FUTURE NASA SATELLITES WILL HAVE TO BE SERVICEABLE IN SPACE.

SATELLITE SERVICING NEEDS

- BASIC IDENTIFIED NEEDS:
  - ABILITY TO HAVE STABLE WORK PLATFORM FOR MANNED EVA ANYWHERE WITHIN PAYLOAD BAY
  - ABILITY, WITH USE OF MMU TO ATTACH TO SATELLITE/STRUCTURES AND HAVE A STABLE WORK PLATFORM
  - ABILITY TO OBSERVE AND/OR HANDLE SATELLITES REMOT FROM ORBITER
  - ABILITY TO TEMPORARILY HOLD AND POSITION SATELLITES/STRUCTURES
  - ABILITY TO MANAGE AND TRANSFER FLUIDS TO SATELLITES
  - ABILITY TO INCREASE MANNED EVA, RMS, AND OTHER SYSTEMS CAPABILITIES THROUGH USE OF TOOLS

- MAJOR CHALLENGES IN DEVELOPMENT OF SATELLITE SERVICES:
  - SYSTEMATIC PROCESS TO DEVELOPMENT EFFECTIVE PARTITIONING OF TASKS - ROBOTS VS PEOPLE
  - MINIMIZE THE INTEGRATION PROCESS WITH ORBITER SYSTEMS/OPERATIONS

SUMMARY

- TRANSPORATION CAPABILITES: MATURE
- PAYLOAD DEPLOYMENT CAPABILITY: MATURE (CURRENTLY ADDRESSING ORBITER/CENTAUR INTEGRATION)
- PAYLOAD RETRIEVAL CAPABILITY: IMMATURE, WITH SOME FLIGHT EXPERIENCE. CONTINUED DEVELOPMENT OF HARDWARE AND OPERATIONAL TECHNIQUES.
- SATELLITE SERVICING CAPABILITY: IMMATURE, EMERGING. CONTINUED SYSTEMATIC DEVELOPMENT OF CAPABILITIES (EQUIPMENT, TOOLS, AND TECHNIQUES)

TETHERED SATELLITE SYSTEM

PROXIMITY OPERATIONS

BY

A. LORENZONI
PSN

C. RUPP
NASA

TETHERED SATELLITE SYSTEM

MISSION OBJECTIVES

The Tethered Satellite System has both science and engineering applications. The first flight is a test of the deployment and retrieval system in the direction away from the earth, a distance of 20 Km, and carries electrodynamic experiment instrumentation. Future flights will deploy the system toward the earth, a distance of 100 Km, to perform atmospheric and geophysical experiments.

TETHERED SATELLITE SYSTEM

MISSION OBJECTIVES

O Engineering Test

To test the capability of the system to perform a variety of space operations to be accomplished from the Shuttle, considering:

- Use of a tethered system with closed loop and man-in-loop
- Deployment of single or multiple masses toward or away from earth, up to 100 KM
- Multiple round trip missions

O Scientific Payloads

To perform experiments and scientific investigation using the tether system for applications such as:

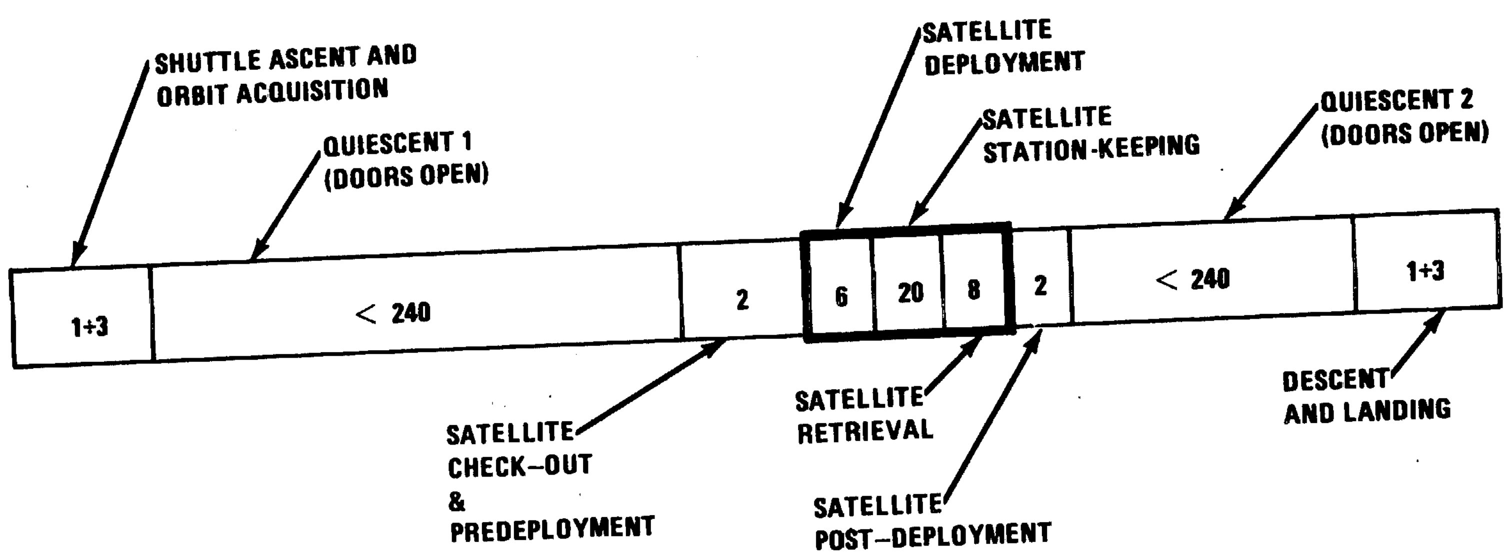
- Magnetometry
- Electrodynamics
- Astmospheric Science
- Chemical Release
- Communications
- Plasmaphysics
- Dynamic Environment
- Aeronomy

MISSION TIMELINE

- Shuttle ascent and orbit acquisition: From liftoff up to final orbit acquisition.
- Quiescent 1: Orbiter with doors open, orbiter dedicated to other payloads. Satellite powered via umbilical deployer for critical parameters monitoring.
- Satellite Checkout: Satellite clamped to deployer. Partial checkout of the satellite via umbilical (RF link excluded), gyro initialization.
- Satellite Pre-deployment and Full Checkout: Boom deployment, satellite checkout at top of the boom via RF-link, gyro calibration.
- Satellite Deployment: Satellite released with in-line thruster aid. During the deployment RF-link shall be maintained for orbiter monitoring data acquisition and command.
- Satellite Stationkeeping: Satellite on-station, ready for experiment conduction.
- Satellite Retrieval: Satellite controlled around yaw axis. In-plane and out-of-plane thrusters operated upon deployer command to control the oscillations (up to 300 M). In the final retrieval phase the in-line thruster will be fired to maintain tension in the tether.
- Satellite Post-Retrieval: Satellite docked at top of the boom. Battery powered-off, boom retrieved. Satellite clamped to docking ring.
- Quiescent 2: As per Quiescent 1 but satellite umbilical not reconnected (no power, no monitor).
- Descent and Landing: Orbiter doors closed, reentry and landing.

MISSION TIMELINE

- THE MISSION PHASES (OPERATIVE AND NON–OPERATIVE SATELLITE) AND RELATED DURATIONS ARE PLANNED AS FOLLOWS:



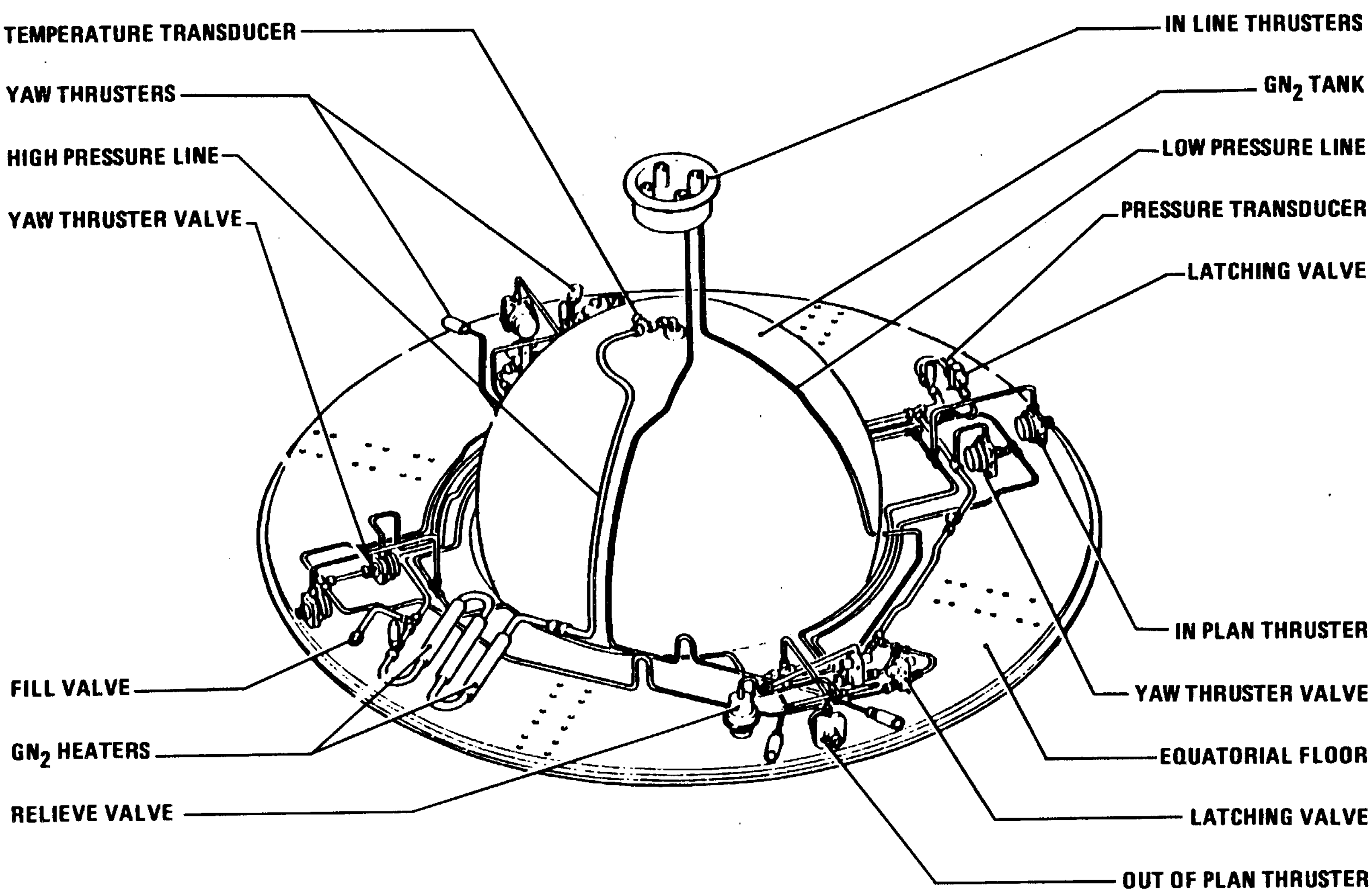
A) IN SPACEWARD ELECTRODYNAMIC MISSION SATELLITE ALTITUDE UP TO 330KM.
B) IN EARTH WARD ATMOSPHERIC MISSION SATELLITE ALTITUDE DOWN TO 120 KM.
C) 28.5° ORBIT INCLINATION IN THE FIRST MISSION.

TSS-S AUXILIARY PROPULSION MODULE

This is a view of the propulsion components with the satellite outer spherical structure removed. The top of the chart faces the Orbiter.

0093-85

TSS--S AUXILIARY PROPULSION MODULE



TSS-S AUXILIARY PROPULSION SYSTEM (APS) CHARACTERISTICS

The system characteristics are shown in the enclosed chart. Most of the gas is used by the in-line thruster and the total amount of gas used is very dependent on the satellite trajectory in the proximity of the Orbiter.

TSS-S AUXILIARY PROPULSION SYSTEM (APS) CHARACTERISTICS

IN-LINE THRUSTERS: 1N AND 2N CONTINUOUS FIRING THRUSTERS ARE USED TO GUARANTEE TETHER TENSION ABOVE 2N DURING DEPLOYMENT AND RETRIEVAL PHASES.

IN-PLANE AND OUT-OF-PLANE THRUSTERS: 2N CONTINUOUS OR PULSATING FIRING ARE USED TO GUARANTEE TRANSLATIONAL STABILITY OF SATELLITE DURING ALL PHASES OF THE MISSION.

YAW THRUSTERS: 0.5 N PULSATING FIRING THRUSTERS ON A 1M LEVER ARM ARE USED TO SPIN AND DESPIN SATELLITE AND CONTROL SPIN ANGULAR VELOCITY.

APS PROPELLANT: 60 KG GASEOUS N_2 WITH A TOTAL IMPULSE OF 32000 NS STORED AT A PRESSURE OF 3000 POUNDS PER SQUARE INCH.

AUXILIARY PROPULSION SYSTEM FUNCTIONAL SCHEMATIC

The enclosed chart shows a schematic of the propulsion system. Isolation valving is designed to allow the in-line thrusters to remain operational in the event a malfunction requires shutdown of the in-plane and out-of-plane thrusters.

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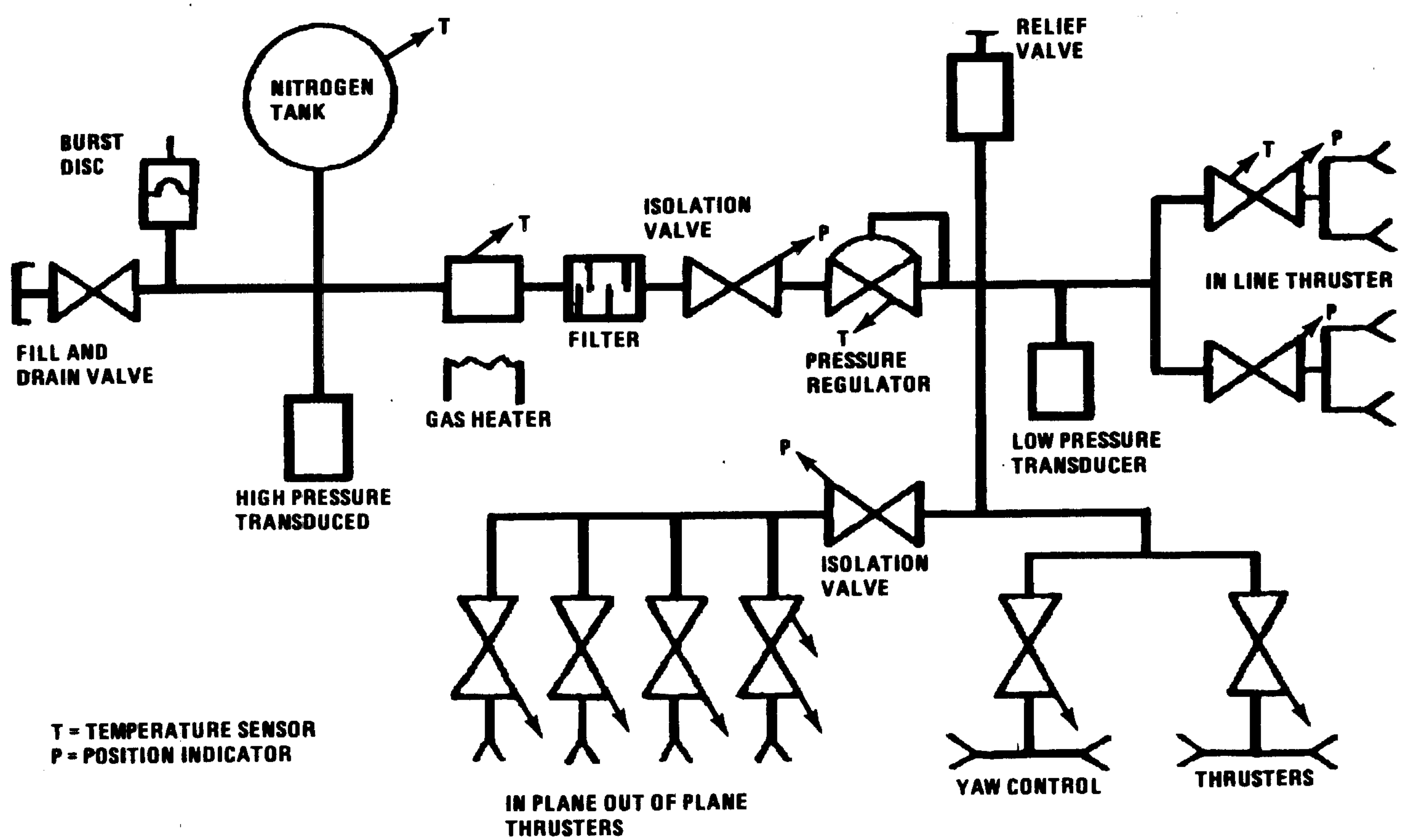
A P S FUNCTIONAL SCHEMATIC



ATTITUDE MEASUREMENT AND CONTROL SYSTEM GENERAL REQUIREMENTS

The AMCS provides a gyro system for measuring satellite attitude and horizon and sun sensors to provide updates. Logic is provided to perform onboard attitude update with some support from the ground. The system provides closed loop control of satellite yaw to maintain the desired spin rate for electrodynamic experiments and translation thruster orientation for deployment and retrieval.

0175-85

ATTITUDE MEASUREMENT AND CONTROL SYSTEM

GENERAL REQUIREMENTS

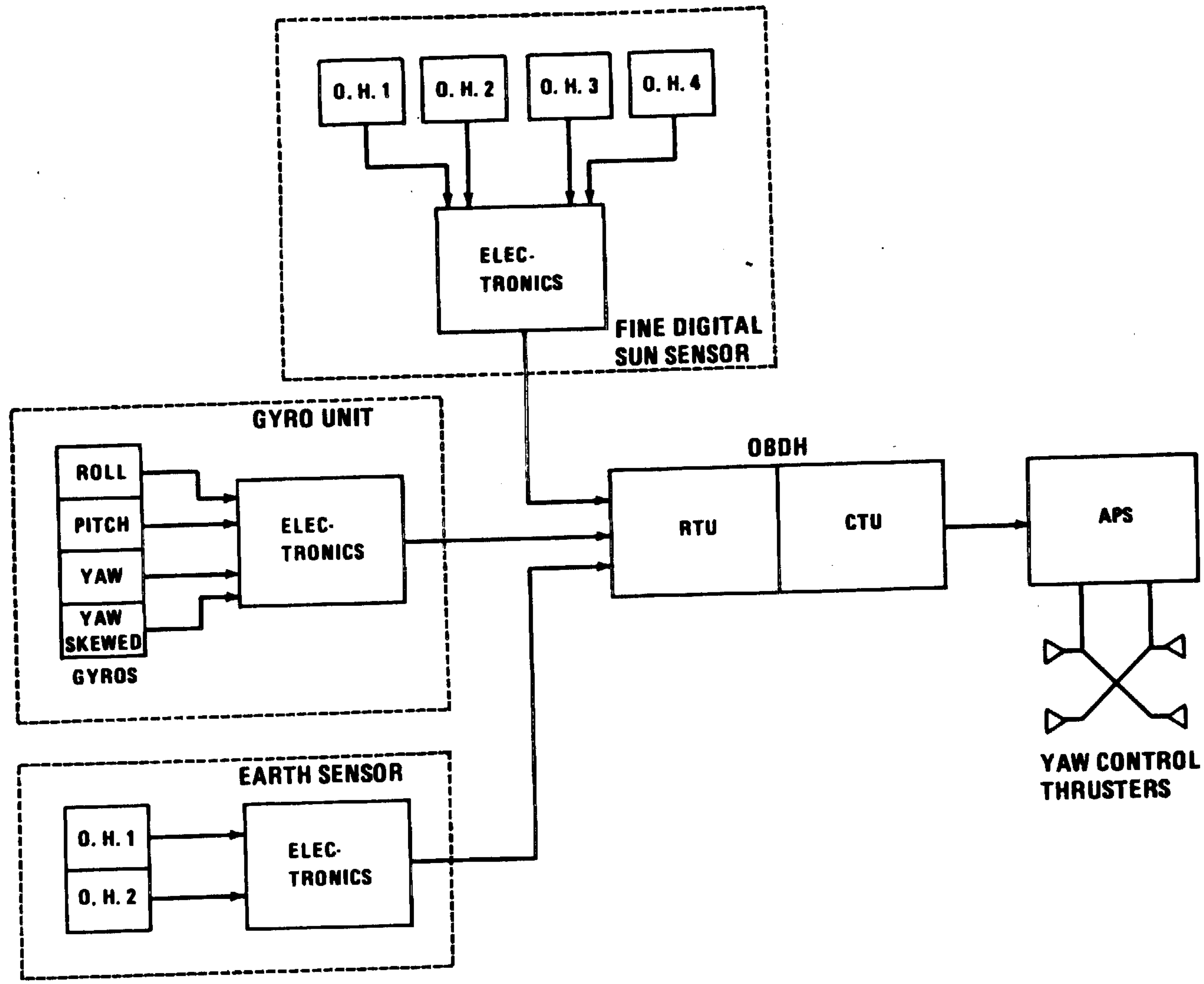
- MEASUREMENT OF THREE AXIS POSITION DURING DEPLOYMENT, ON-STATION AND RETRIEVAL FOR BOTH ELECTRODYNAMIC AND AERODYNAMIC MISSIONS
- PERFORM ACTIVE CONTROL OF YAW POSITION DURING DEPLOYMENT AND RETRIEVAL FOR BOTH MISSIONS, AND ON-STATION FOR THE ELECTRODYNAMIC MISSION
- PERFORM ACTIVE CONTROL OF YAW SPIN RATE DURING ELECTRODYNAMIC MISSION

ATTITUDE MEASUREMENT AND CONTROL SYSTEM

The enclosed chart is a schematic representation of the AMCS. A rate gyro system measures satellite attitude and horizon sensors, updates the pitch and roll axes, and a sun sensor updates the yaw axis.

5-85

ATTITUDE MEASUREMENT AND CONTROL SUBSYSTEM BLOCK DIAGRAM



ATTITUDE MEASUREMENT AND CONTROL SYSTEM PERFORMANCE

The enclosed chart lists the msurement accuracy and yaw control accuracy requirements.

0176-85

ATTITUDE MEASUREMENT AND CONTROL SYSTEM PERFORMANCE

MEASUREMENT ACCURACY

- $\pm 1^{\circ}$ POSITION (3σ) ON BOARD PROCESSING ALL AXES, ALL PHASES, BOTH MISSIONS
- $\pm 0.3^{\circ}$ POSITION (3σ) WITH GROUND PROCESSING ALL AXES, ALL PHASES, BOTH MISSIONS
- $\pm$ 0.01 RAD/SEC SPIN VELOCITY (0 TO 1 RPM) ELECTRODYNAMIC MISSION, ON STATION

CONTROL ACCURACY

- $\pm 3^{\circ}$ IN YAW DURING DEPLOYMENT AND RETRIEVAL BOTH MISSIONS
- $\pm$ 0.01 RAD/SEC SPIN VELOCITY (0 TO 1 RPM) ELECTRODYNAMIC MISSION, ON STATION
- $\pm 3^{\circ}$ IN YAW ON STATION (ELECTRODYNAMIC MISSION ONLY)

TSS RETRIEVAL

AUTOMATIC VERSUS MANUAL CONTROL

Originally, an automatic retrieval scheme was proposed using the orbiter rendezvous radar as a satellite position sensor and a TSS supplied computer in the payload bay as the control computer. This requires orbiter software changes to pass radar data to the control computer and other software changes to pass computer commands to the satellite through the payload interrogator. This scheme was abandoned because of the high costs associated with the software changes and the development of a terminal docking sensor. In addition, crew training for a manual backup mode appeared necessary because of the large amount of simplex hardware involved and because of the collision hazard.

Manual control schemes were developed for the terminal docking phase using either the orbiter for controlling the the relative position or the satellite. The decision on which end to control has not been made but hardware designs are being considered to allow either end to be controlled.

The subject of this presentation now turns to the scheme to be used for the initial retrieval phase which begins with the fully deployed tether length and continues to the point at which visual cues from television can be used.

TSS RETRIEVAL
AUTOMATIC VS MANUAL CONTROL

AUTOMATIC CONTROL

- O REQUIRES SOFTWARE CHANGES ON ORBITER
- O REQUIRES A DOCKING SENSOR
- O CREW REQUIRED FOR MANUAL BACKUP

MANUAL CONTROL

- O NO NEW ORBITER SOFTWARE REQUIRED
- O ADDITIONAL TELEVISION COVERAGE REQUIRED

TETHERED SATELLITE SYSTEM

FIRST FLIGHT COMMUNICATIONS AND TRACKING APPROACH

The manual control scheme uses the Orbiter rendezvous radar for tracking the satellite at ranges beyond 100 meters. Thruster firing commands are issued by the crew as required. The satellite maintains yaw stabilization using a satellite IMU as the sensor.

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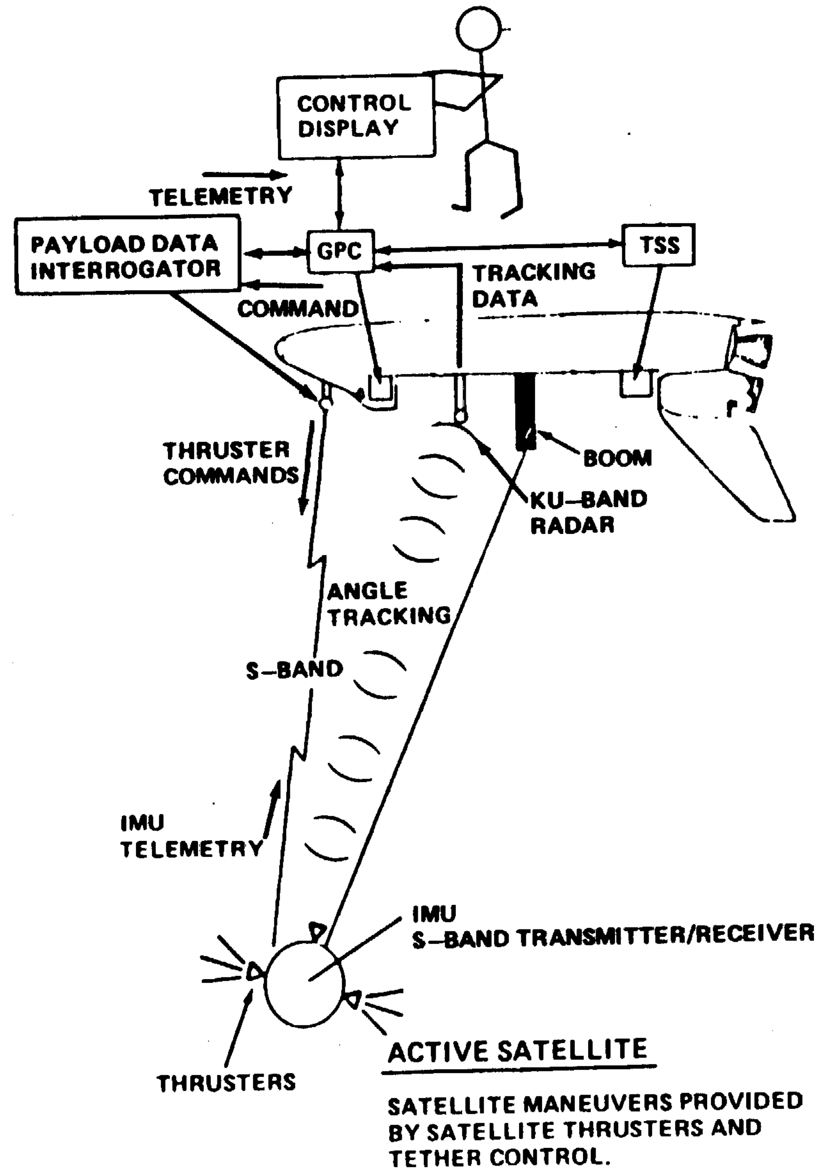
TETHERED SATELLITE SYSTEM
FIRST FLIGHT COMMUNICATIONS AND TRACKING APPROACH



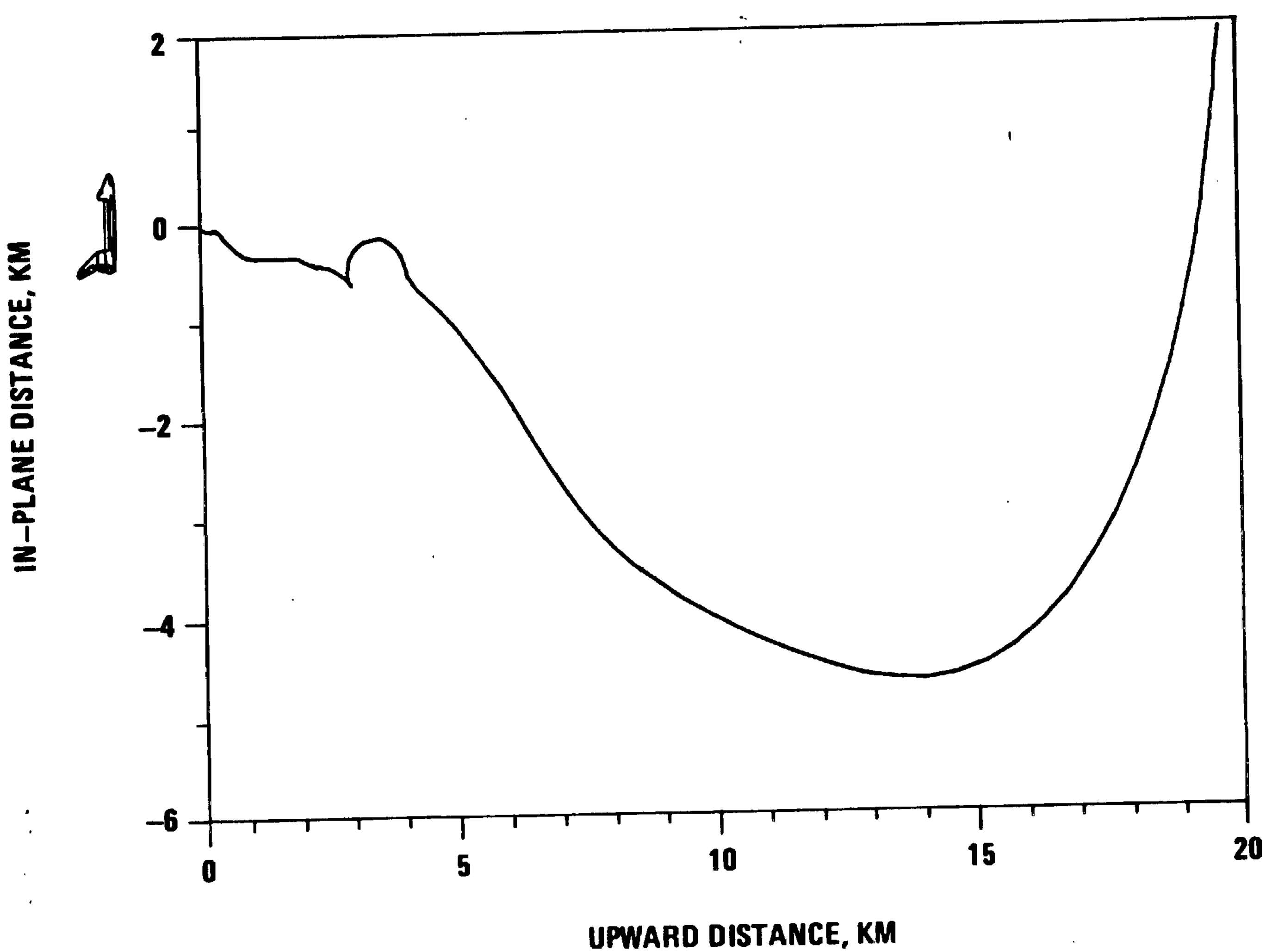
- REAL TIME SATELLITE CONTROL USES GPC
  - DISPLAY
  - CONTROL
- 16 KBPS TELEMETRY
- 2 KBPS COMMAND

AUTOMATIC RETRIEVAL TRAJECTORY

The next two charts show the trajectory for an automatic retrieval system. These are shown to point out some characteristics of the trajectories which will prove useful in the design of a manual control scheme. The automatic control scheme used here uses angular rate and angle phase plane logic to determine when to fire the satellite thrusters. Initial swing angle transients manifest themselves as constant amplitude excursions until control is exercised near the end of retrieval.

0190-85

IN–PLANE RETRIEVAL TRAJECTORY
AUTOMATIC CONTROL



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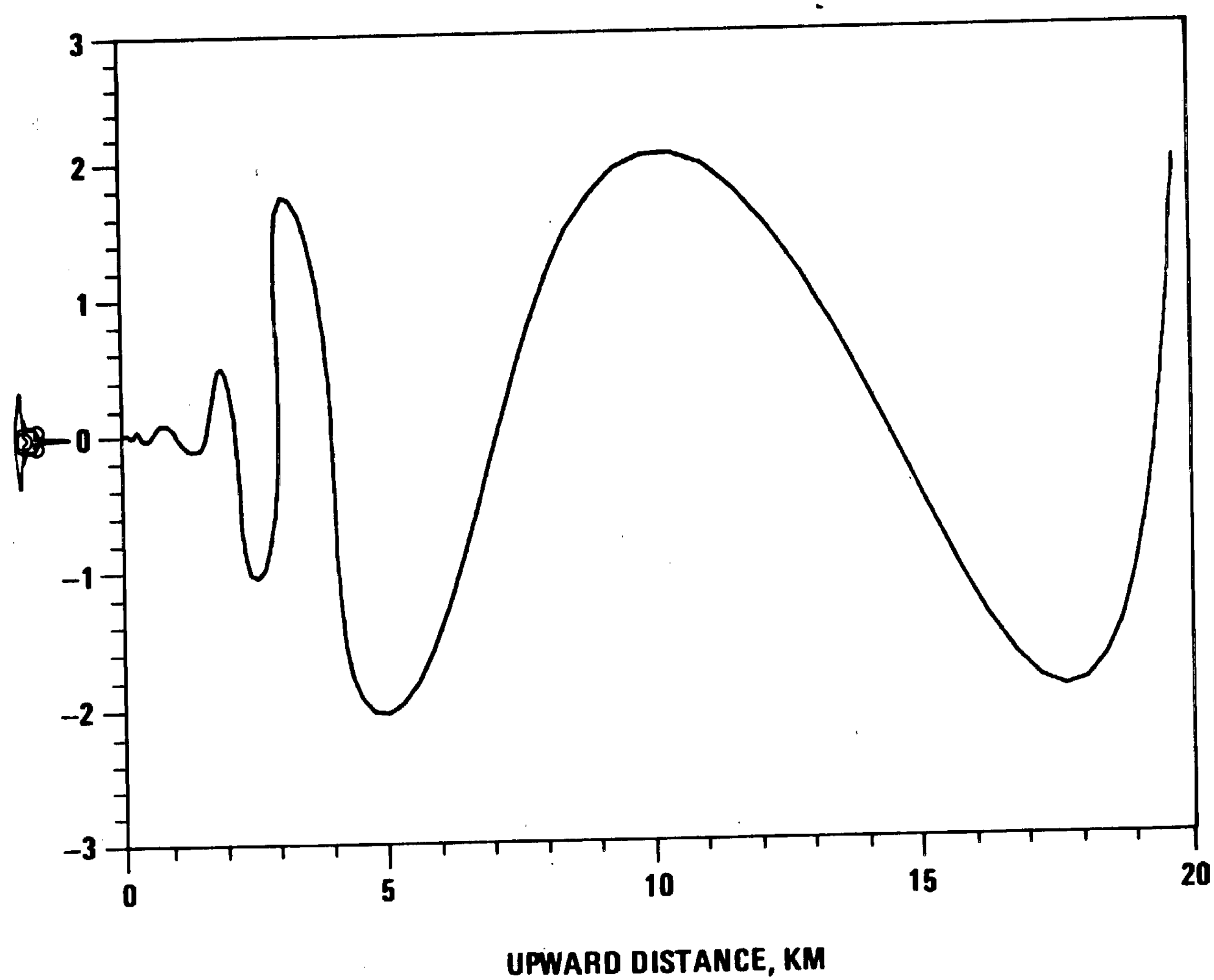
0191-85

OUT–OF–PLANE RETRIEVAL TRAJECTORY AUTOMATIC CONTROL



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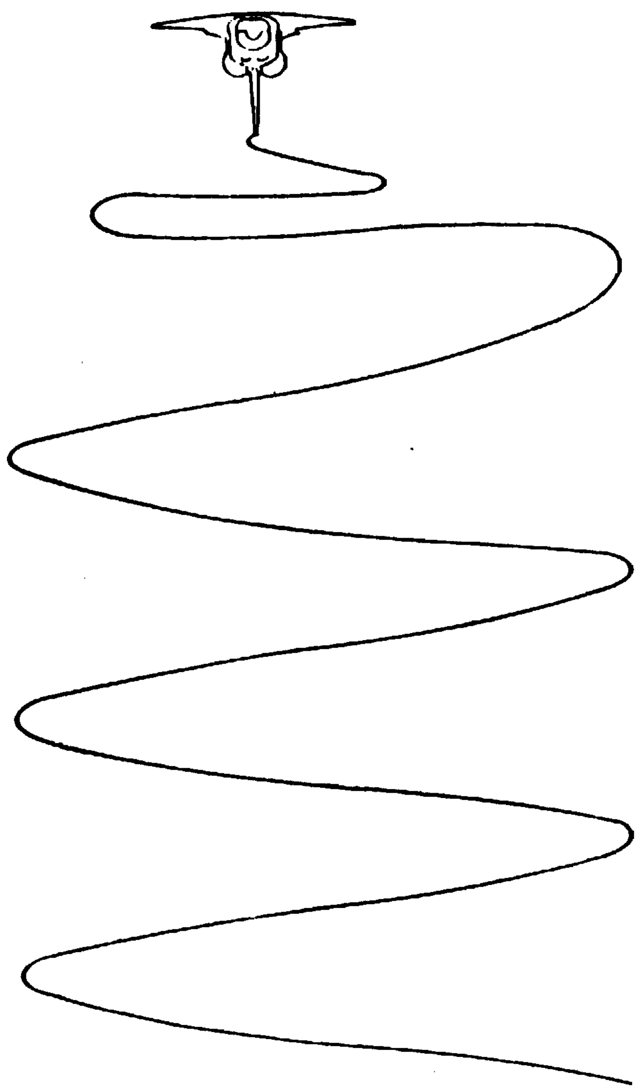
The periodic constant amplitude excursion can be damped early in the retrieval but orbiter based tracking systems can have errors which degrade performance at long distances. As the retrieval progresses, the angular tracking data gets larger so the sensor data to error ratio gets larger. For a sensor such as the rendezvous radar the swing angle should be greater than 3 degrees with perhaps 10 degrees as a desired angle at which to exercise control.

The control technique which will now be discussed is sometimes called deadbeat control. Swing angle and length estimates are used to compute thruster firing commands which, when applied at the proper time, can kill the swinging motion with one thruster actuation. Allowance for sensor and thrust errors will require typically 3 to 4 actuations. Indeed, to minimize the chances of wasting propellant, one should intentionally undershoot the control to allow the sensor data to improve during subsequent swings.

0090-85

MANUAL CONTROL

20000→300 M



OBSERVATIONS

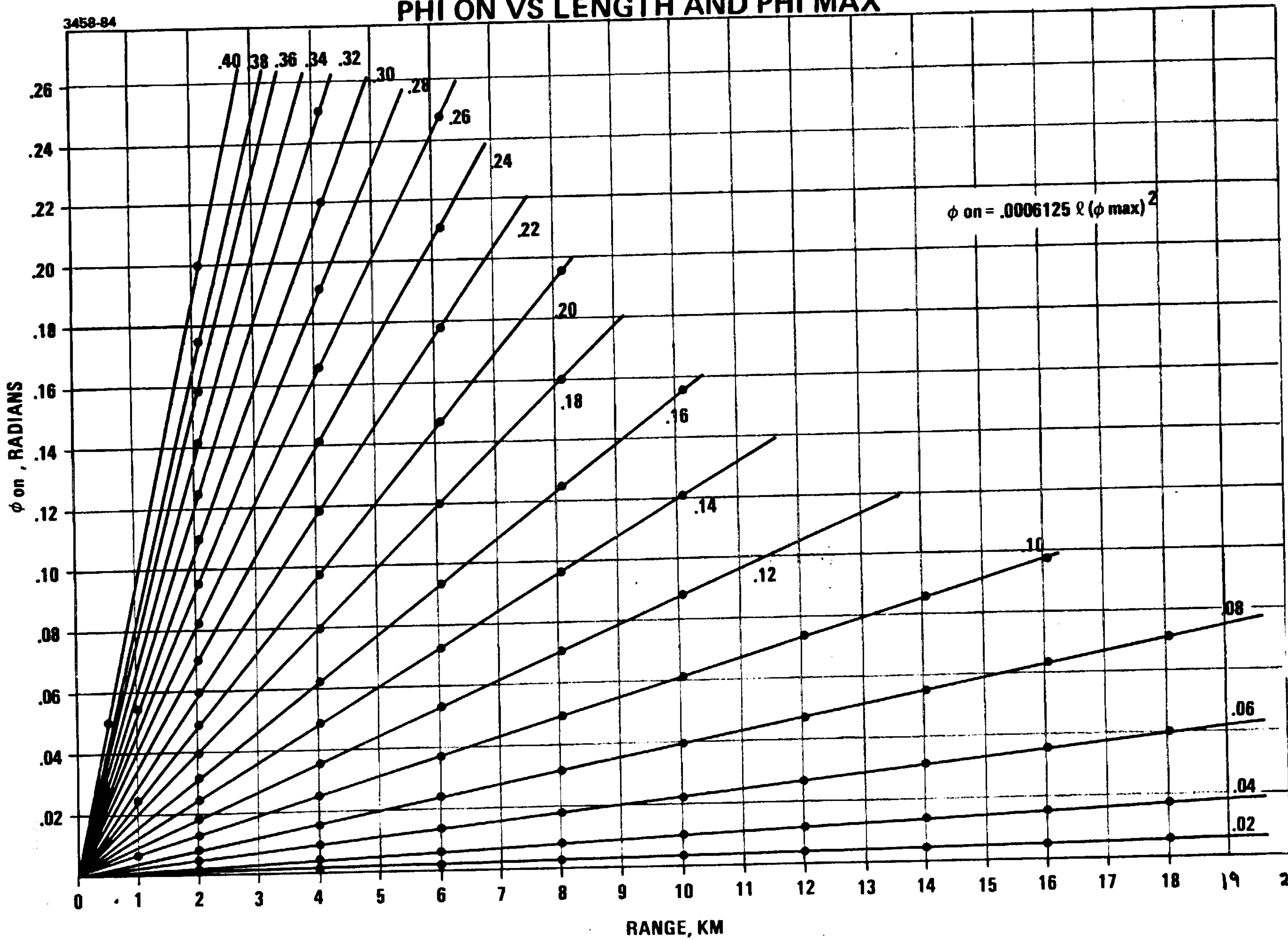
- THEORETICALLY, OUT–OF–PLANE LIBRATION CAN BE DAMPED EARLY IN THE RETRIEVAL.
- CONTROL SHOULD NOT BE APPLIED UNTIL PEAK SWING EXCEEDS 3 DEGREES BECAUSE OF RADAR ERRORS.
- CHANCES OF WASTING PROPELLANT ARE MINI–MIZED BY ALLOWING SWING TO GROW TO 8 TO 10 DEGREES BEFORE CONTROLLING BECAUSE OF IM–PROVED MEASURING ACCURACY.
- ADJUST THRUSTER ACTIVATION TO LEAVE 2 DE–GREES SWING PREVENTS WASTED IMPULSE CAUSED BY ERRORS.
- QUITE A FEW OBSERVATION PERIODS EXIST FOR PREDICTING THRUSTER ACTUATION.
- RESIDUAL ERRORS AT THE END OF A THRUSTER ACTUATION CAN BE REMOVED DURING SUBSE–QUENT OPPORTUNITIES.

NOMOGRAPHS

Nomographs can be provided to estimate thruster firing commands. Closed form solutions have been found for the swing amplitude to turn on a thruster such that the amplitude and rate are reduced to zero at the same time. It is also desirable to estimate the duration of firing so that the thruster can be commanded off at a specified time which should be more reliable than sensing angles and angular rates around zero. Calculation of the firing time involves elliptic integral evaluation or numerical integration.

For short ranges below 1,000 meters adequate performance is obtained by firing the thruster near zero angle because the firing time is short compared to the swing period.

LONG RANGE PHI THRUSTER CONTROL
PHI ON VS LENGTH AND PHI MAX



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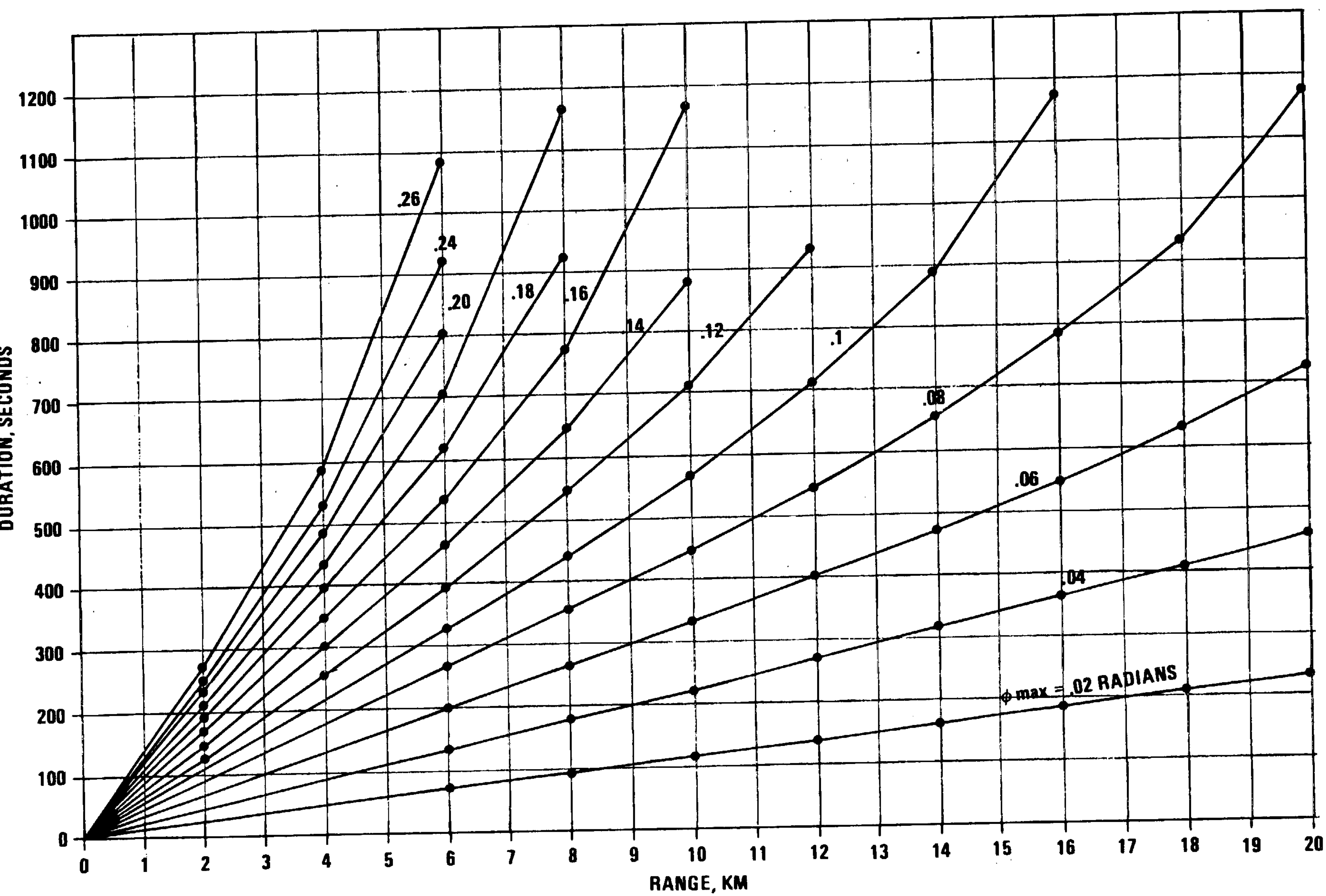
LONG RANGE PHI THRUSTER CONTROL DURATION VS LENGTH AND PHI MAX



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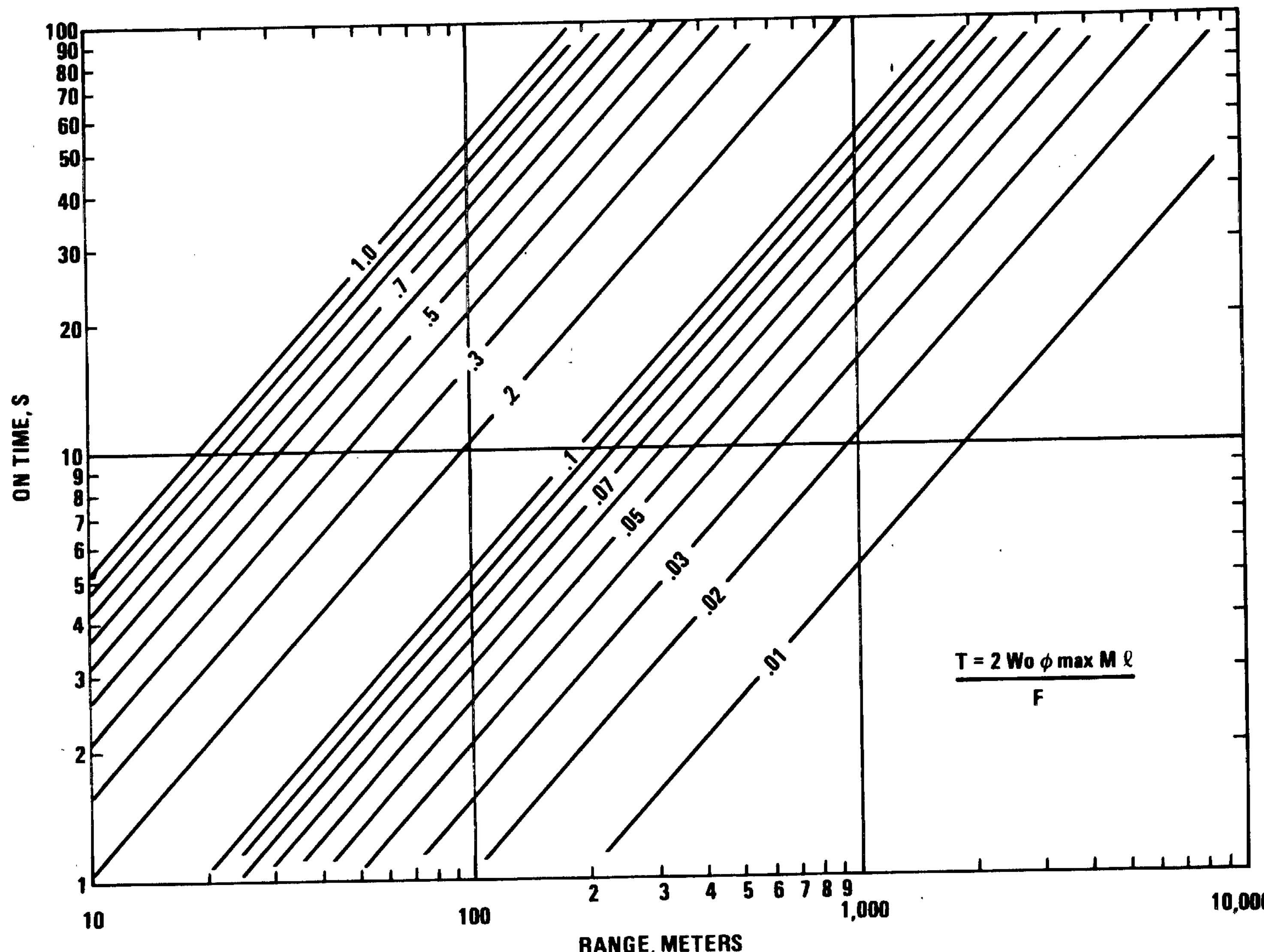
460-84

SHORT RANGE PHI THRUSTER FIRING TIME
USE ± .002 RADIAN FOR PHI ON



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MANUAL CONTROL PERFORMANCE

A simulation at MSFC was modified to display in-plane, out-of-plane, and range data similar to radar data. Manual control using the satellite thrusters and the nomographs was exercised for several initial conditions and performance is compared to an automatic phase plane logic. The simulation does not include hardware errors in the radar or thruster system. In-plane and out-of-plane trajectories are shown in the following charts.

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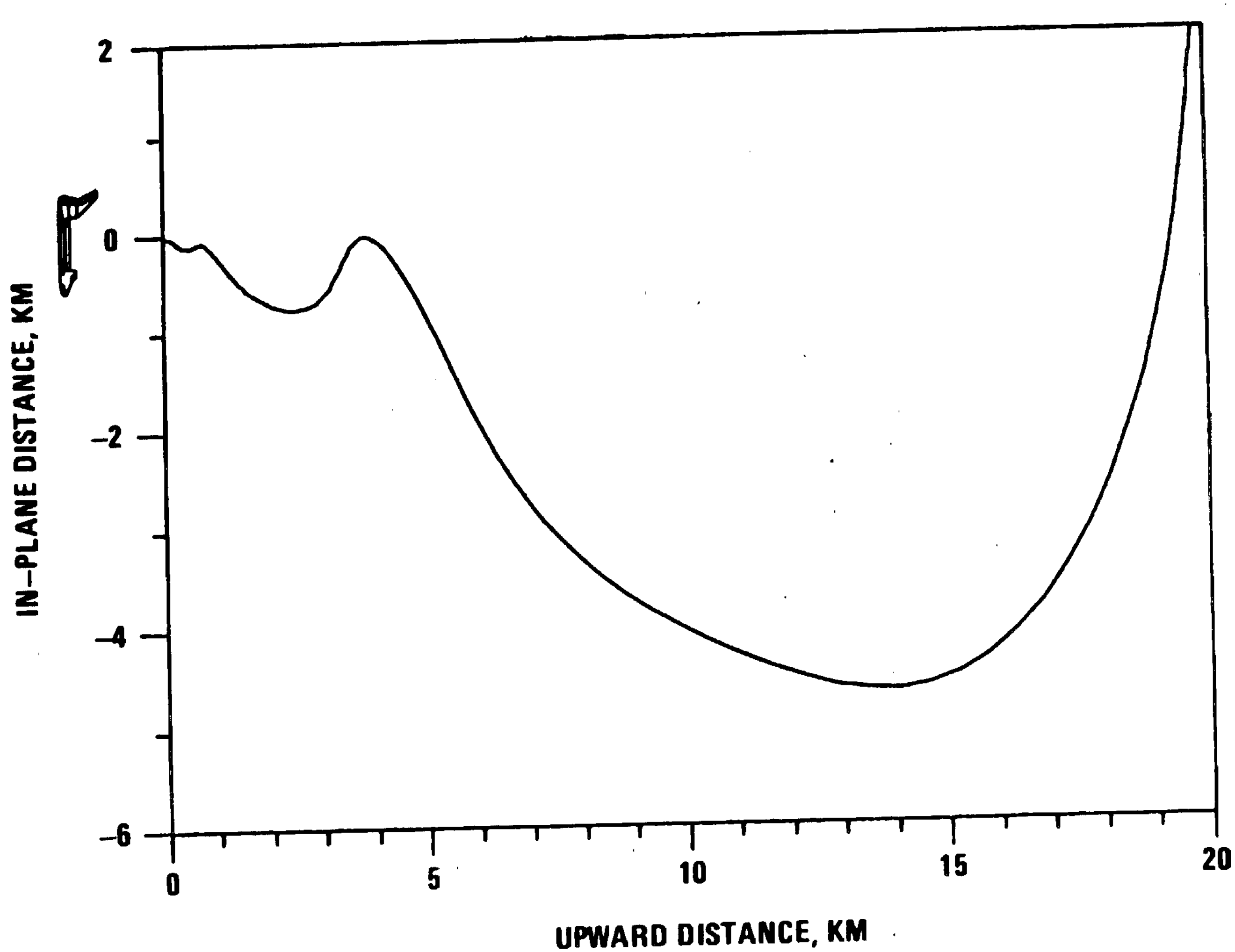
IN–PLANE RETRIEVAL TRAJECTORY
MANUAL CONTROL



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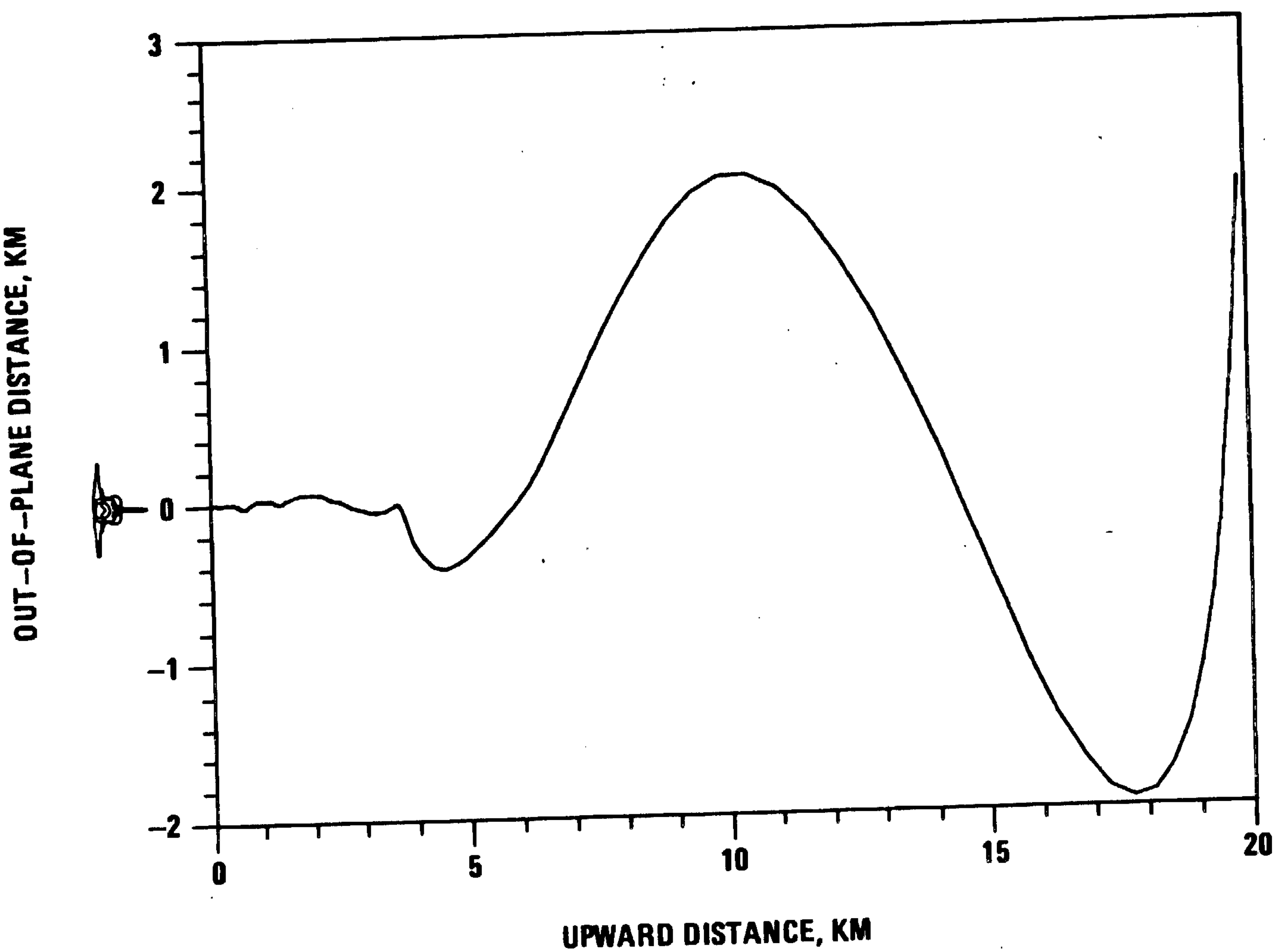
01

OUT–OF–PLANE RETRIEVAL TRAJECTORY
MANUAL CONTROL



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CONCLUSIONS

The feasibility of this manual control scheme has been shown in simplified simulation. The next step is to verify the operation in more complete simulations. Careful thought must be given to the design of the simulation because of the very long real times involved. Hardware errors and the use of realistic displays should be incorporated and some thought should be given to running faster than real time for the non-time critical portions of the simulation.

CONCLUSIONS

- Feasibility of manual control has been shown
- Verification is now required

3-52

OMV: THE KEY TO SATELLITE SERVICING

A. G. STEPHENSON

OMV: The Key to Satellite Servicing

The OMV is a key element in NASA's plans to maintain and extend the life of satelliites through on-orbit servicing. Initially, satellites will be serviced by returning them to the Orbiter (e.g. recent repair of the Solar Max Satellite). With the arrival of the Space Station satellites will be brought there for repair. Ultimately, the repair of satellites will be accomplished remotely at the operating orbit. For servicing at the Orbiter or Space station, the OMV will be the retrieval/ redeployment vehicle. This presentation addresses the docking/retrieval and deployment operations as well as servicing operations at the Orbiter or Space Station. Servicing of GRO and AXAF are shown as specific examples of programs that will benefit from OMV-enabled servicing.

OMV: THE KEY TO SATELLITE SERVICING

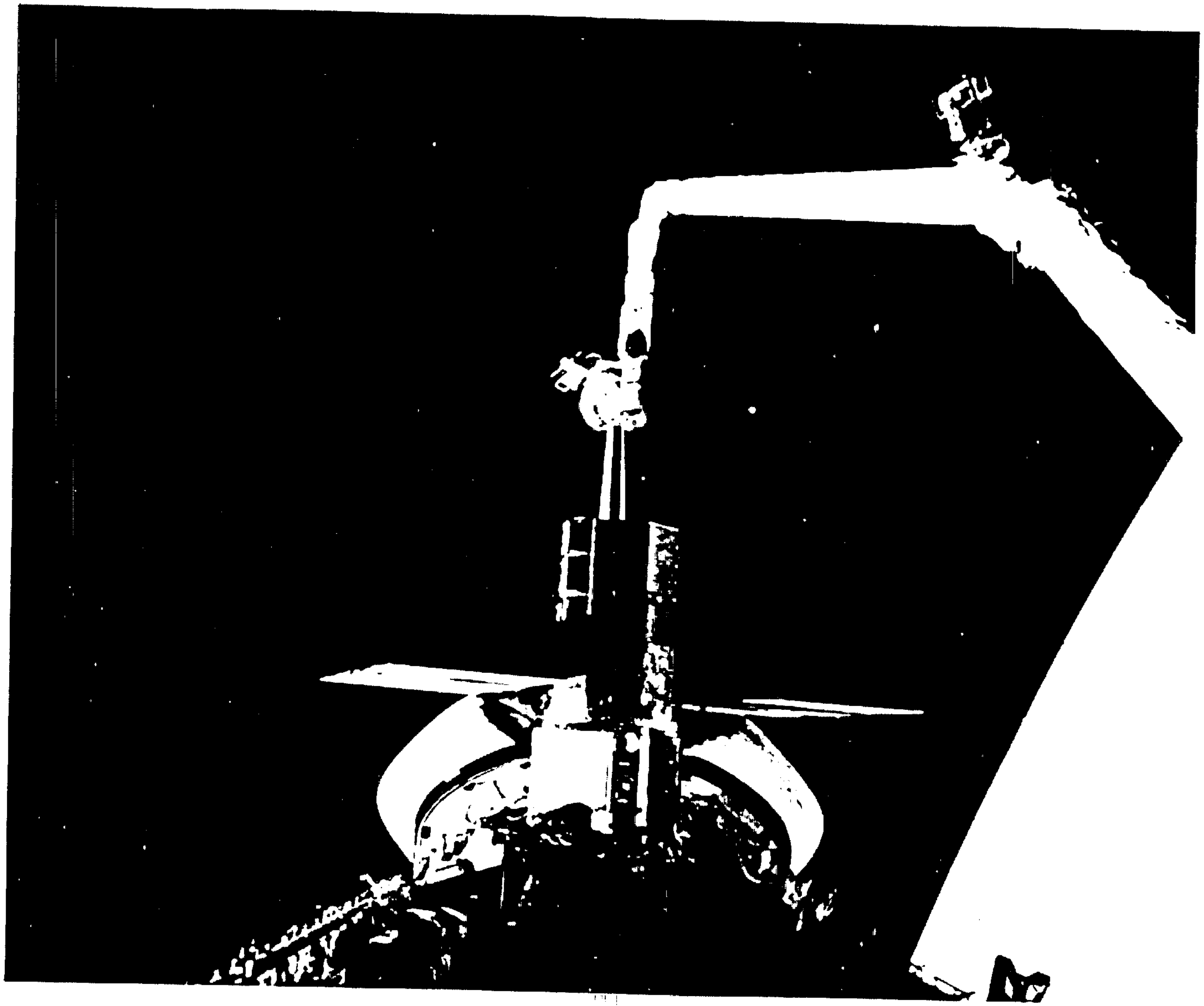
THE ORBITAL MANEUVERING VEHICLE IS A KEY ELEMENT IN PLANS TO MAINTAIN AND EXTEND THE LIFE OF SATELLITES THROUGH ON-ORBIT SERVICING.

- SATELLITES INITIALLY RETURNED TO ORBITER FOR SERVICE
- SATELLITES WILL BE SERVICED AT SPACE STATION
- UTLIMATELY, SATELLITES WILL BE REMOTELY SERVICED AT THE OPERATING ORBIT

Solar Max Retrieval and Repair

The recent Westar, Palapa and Solar Max retrieval missions have shown how useful man and his tools can be. With Solar Max, the ability of man to repair a satellite in Space was dramatically demonstrated. The recent Shuttle flight which demonstrated fluid transfer is a first step toward enabling Satellite life extension through replenishment of vital, station keeping propellants. Clearly, Space operations are entering a new era where satellites can be serviced and brought back to life. The Shuttle has ushered in this new era. But what about retrieval and repair missions at altitudes that the Shuttle cannot reach?

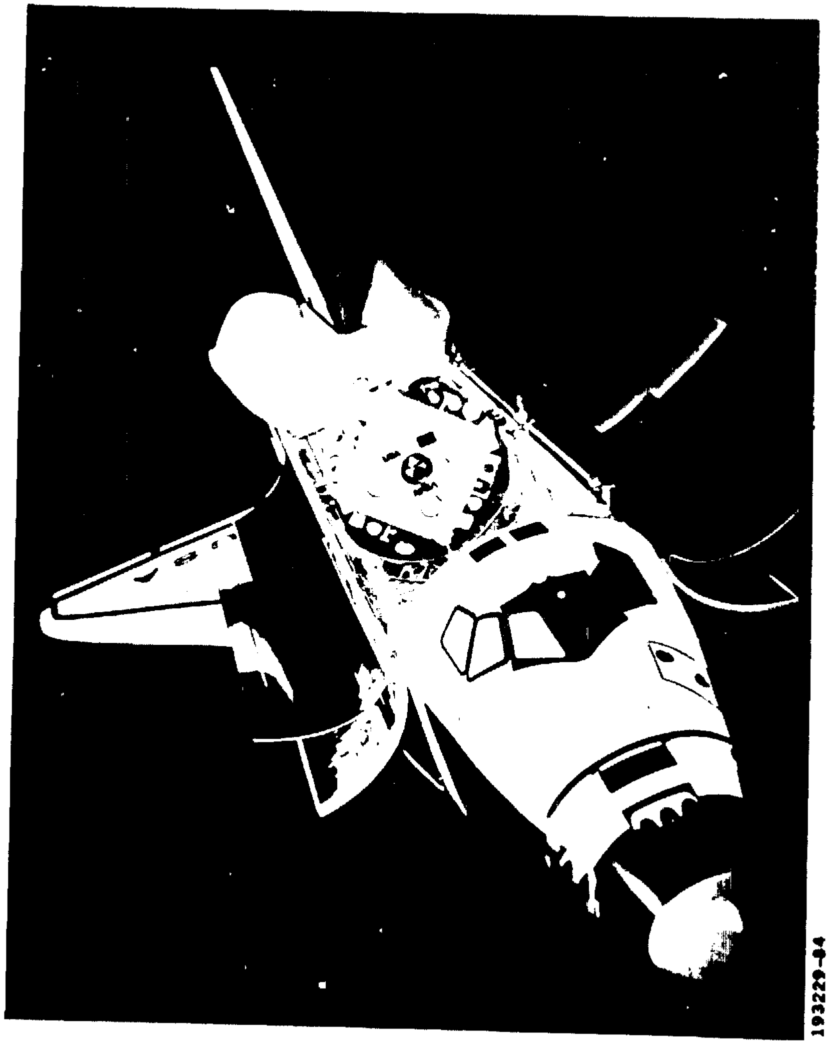
Solar Max Retrieval & Repair



OMV - Extending STS Capability

ENTER THE OMV, or Orbital Maneuvering Vehicle. The OMV is designed to extend man's reach up to 1400 nautical miles above the Shuttle altitude. One can think of the OMV as a 1400 mile Shuttle remote manipulator system (RMS) since it can perform the same functions as the RMS. As shown for the 5000 lbs. payload example, the OMV altitude reach can be traded for plane changes up to 7.5 degrees. For a 25,000 lb. payload, the altitude reach and plane change capability is cut in half.

TRW



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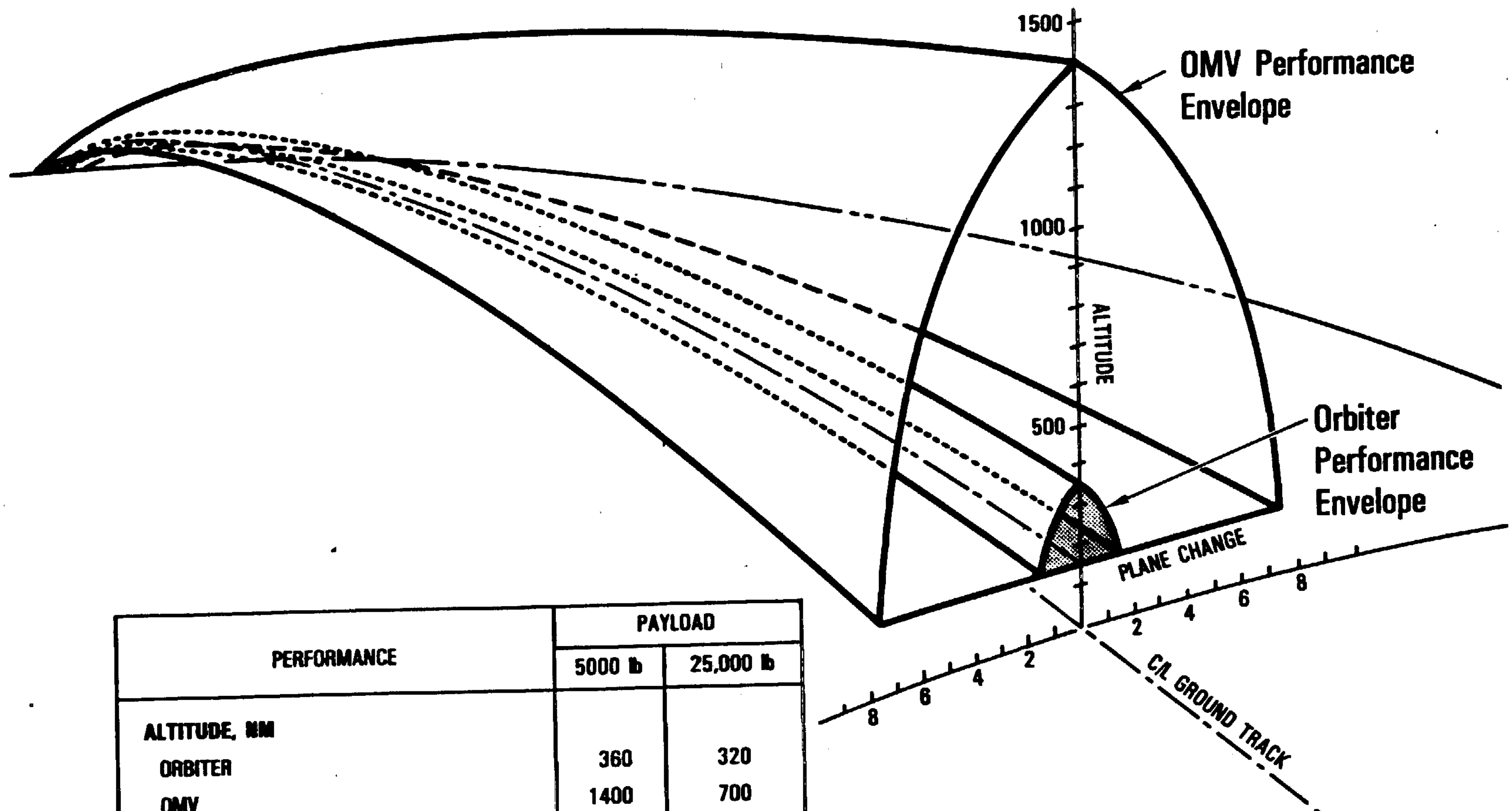
OMV

Extending Orbiter Capability

OMV LEO Performance Envelope



PERFORMANCE	PAYLOAD 5000 lb	PAYLOAD 25,000 lb
ALTITUDE, NM		
ORBITER	360	320
OMV	1400	700
PLANE CHANGE, DEG		
ORBITER (ONE WAY WITH P/L)	1.4	1.2
OMV (TWO WAY; P/L OUT; OMV RETURN)	7.5	4.0

OMV - A Smart Tow Truck for Space

When assigned to retrieve a spacecraft or platform and return it to the Orbiter, the OMV steps through three operational modes to rendezvous and dock with the target vehicle.

1) Orbit Transfer using the Global Positioning System (GPS):

After release from the Orbiter, the OMV performs orbit transfer to the vicinity of the target vehicle using on-board Guidance and Navigation (G&N) software. The target ephemeris is pre-loaded in its position. On-board G&N algorithms compute the proper orbit changing propulsion maneuvers to bring about rendezvous of the two vehicles.

2) Radar Transfer & Rendezvous

Radar is then used to bring the vehicles close enough to allow sighting by the remotely situated pilot.

3) Pilot Controlled Docking:

Final docking is controlled by a ground-based or space station based pilot using on-board TV cameras to aid him as he commands the vehicle through the final docking maneuvers. Communication will be through the geosynchronous tracking data relay satellite. The target spacecraft is mechanically attached to the OMV using a docking mechansim at the center of the vehicle that is much like the Orbiter Remote Manipulator System end-effector.

OMV – A Smart Tow Truck for Space

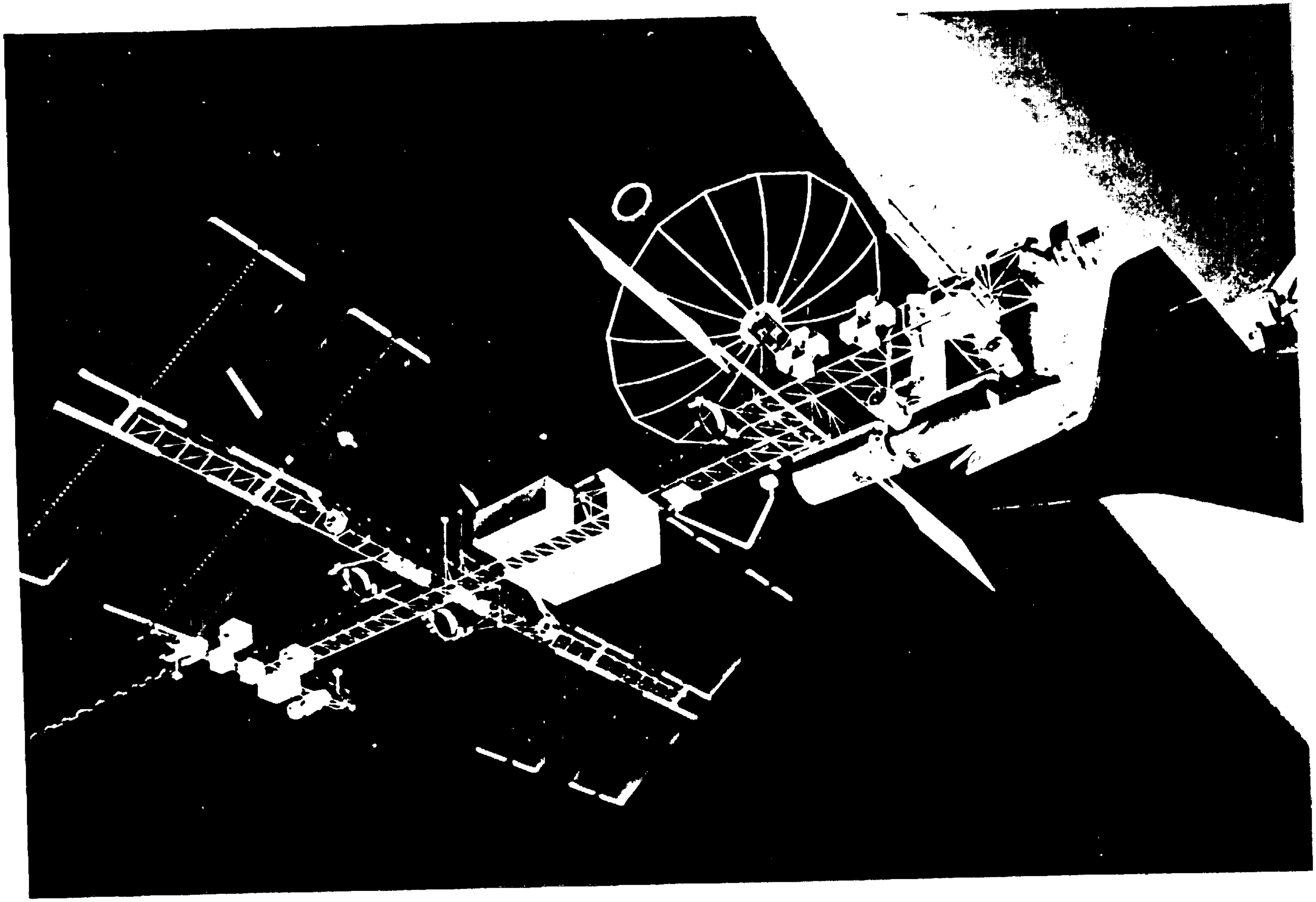
193269-84

OMV - A Key Space Station Element

As the Space Station becomes operational, OMV will perform tow truck operations in a similar manner, retrieving satellites for repair and returning them to their desired orbit after servicing at the Space Station. Co-orbiting space platforms will be "tended" by the OMV - maintaining this formation flying and changing out experiments and processed materials.

OMV — A Key Space Station Element

TRW



Servicing Missions Utilizing the OMV

TRW has recently completed a Satellite Servicing study for Marshall Space Flight Center. Three representative mission scenarios were investigated which encompass the most relevent aspects of servicing functions to be performed with the OMV from the Space Station itself or remotely at the orbital position of the target satellites. The reference mission scenarios are:

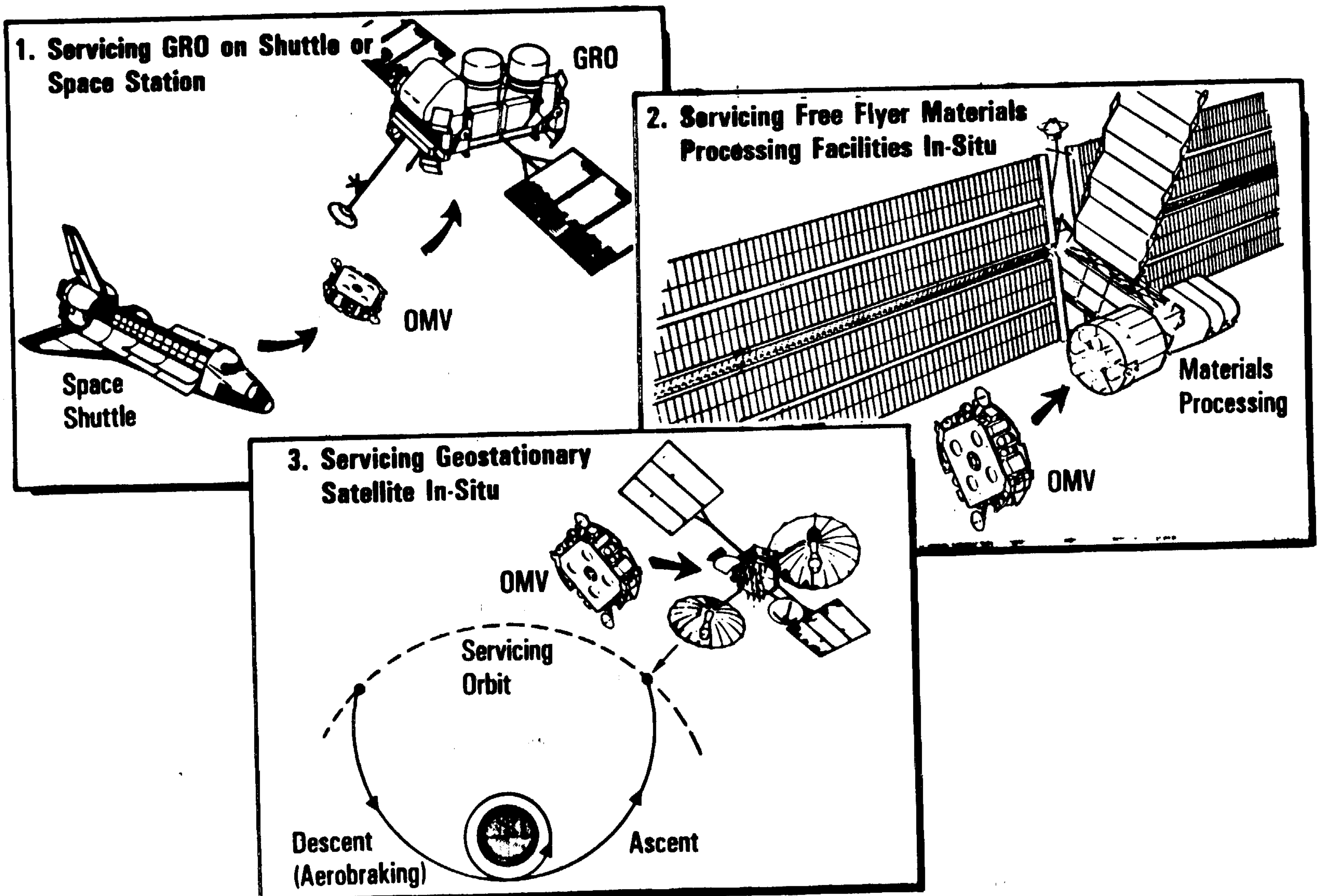
1. Servicing of a low-earth-orbit (LEO) satellite, e.g., the Gamma Ray Observatory (GRO), at the Shuttle or Space Station with satellite retrieval accomplished by the OMV.

2. Servicing of a free-flying, co-orbiting materials processing facility, in situ, including periodic resupply and harvesting of finished products.

3. OMV servicing of a geostationary satellite, in situ, by using a recoverable Orbital Transfer Vehicle to perform the ascent and descent to/from synchronous orbit, and an OMV carrying supplies, replacement parts, tools and support equipment such as a remote/robotic servicer.

The reference missions are derived from a set of servicing technology development missions (TDMs) previously studied by TRW under contract to NASA/MSFC.

Servicing Missions Utilizing the OMV



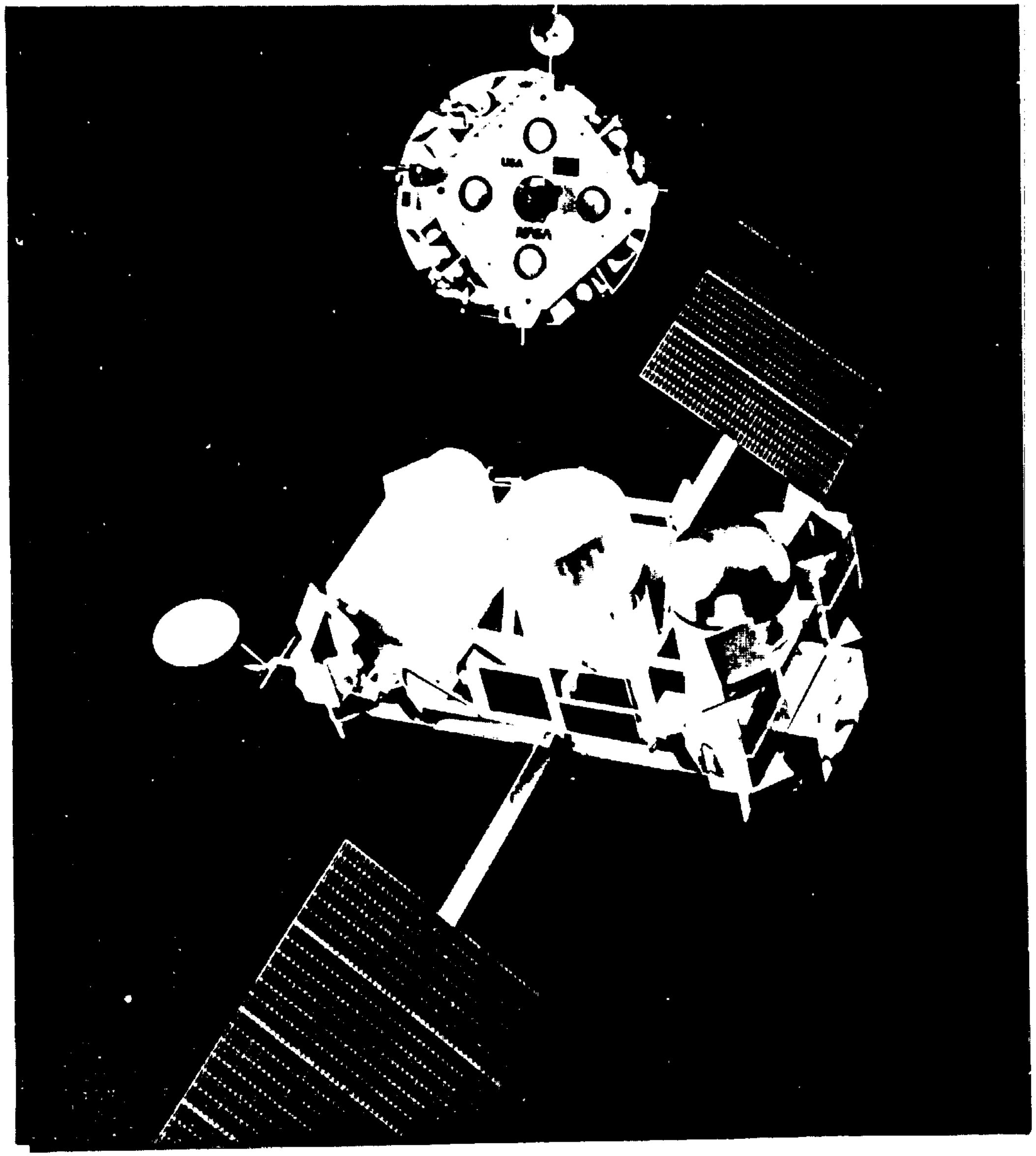
Gamma Ray Observatory (GRO) Servicing

The Gamma Ray Observatory, being developed by TRW under contract to Goddard Space Flight Center, is a candidate to be retrieved by the OMV for servicing at the Shuttle*. After return to the Shuttle, the GRO will be placed on a flight support system cradle. Two Orbital Replacement Units (ORUs), the Modular Power System (MPS) and the communication and data handling (C&DH) module can be changed out in orbit. These modules are very nearly the same as those used on the Solar max spacecraft. If need be replacement will be accomplished by EVA astronauts in the same way replacement was accomplished on the solar max missions.

*Although GRO has integral propulsion and this does not require an OMV for return to the Shuttle, it is a candidate to demonstrate OMV retrieval ability toward the end of the GRO mission lifetime.

TRW

GRO Retrieval



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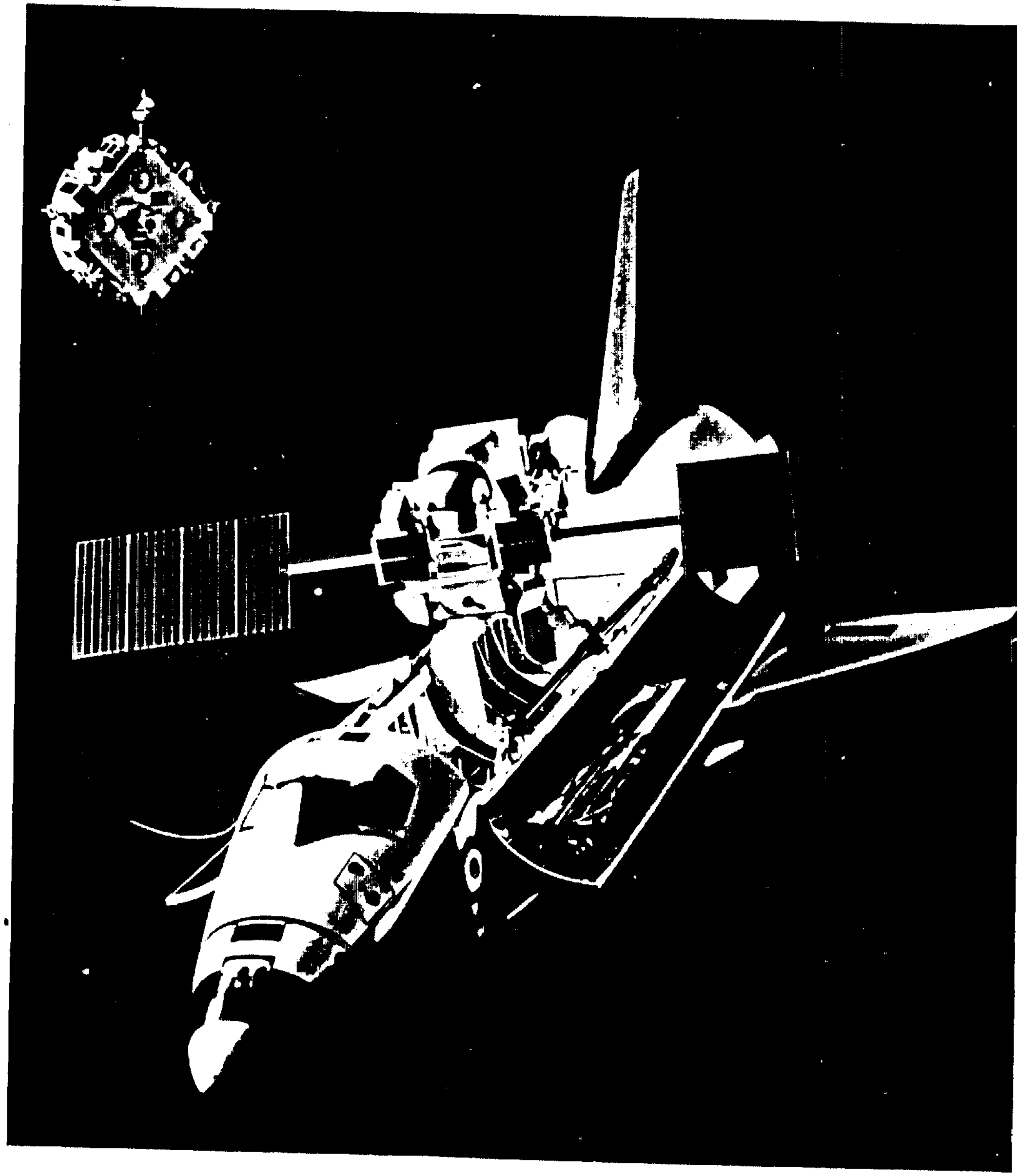
GRO Servicing

TRW



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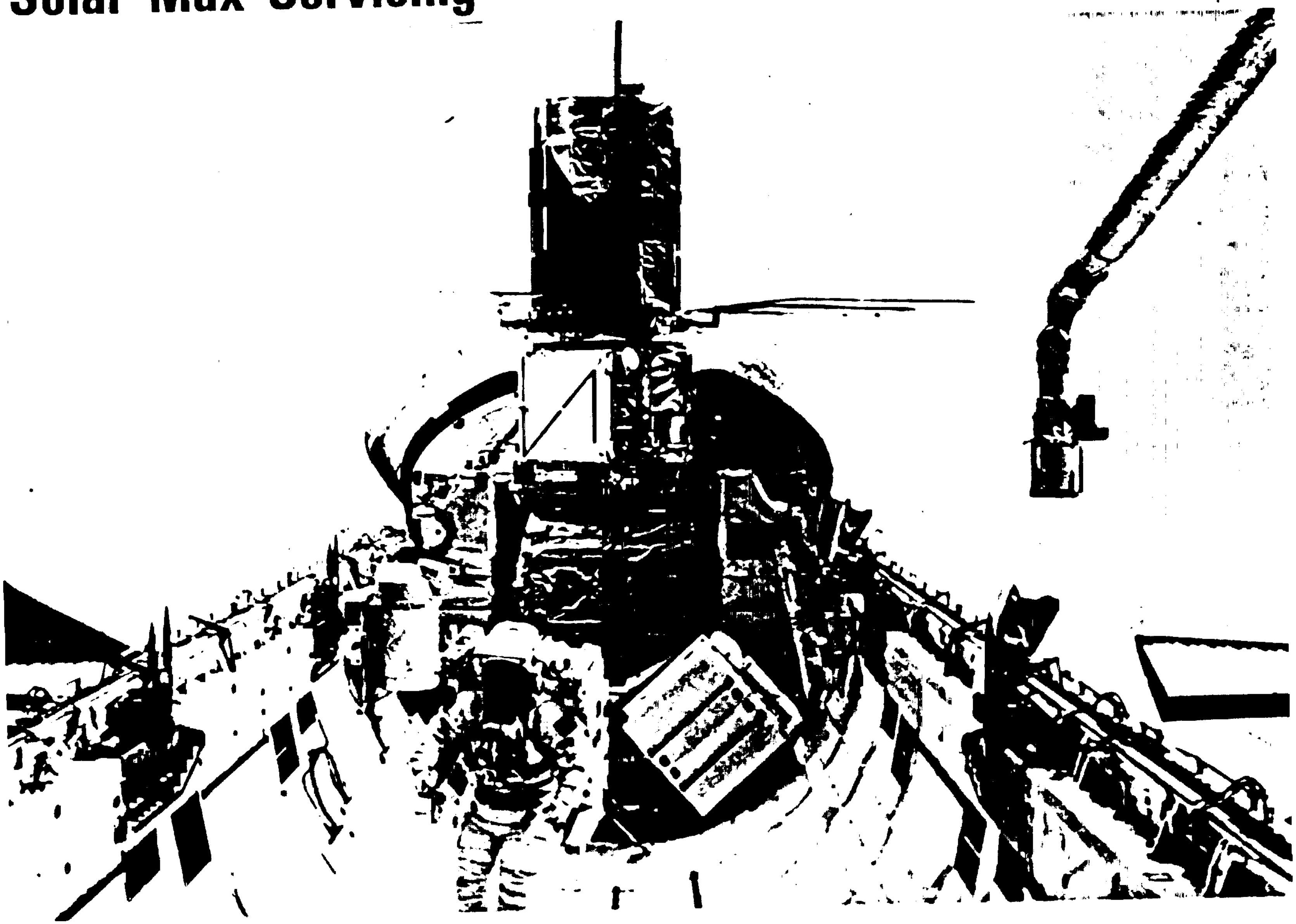
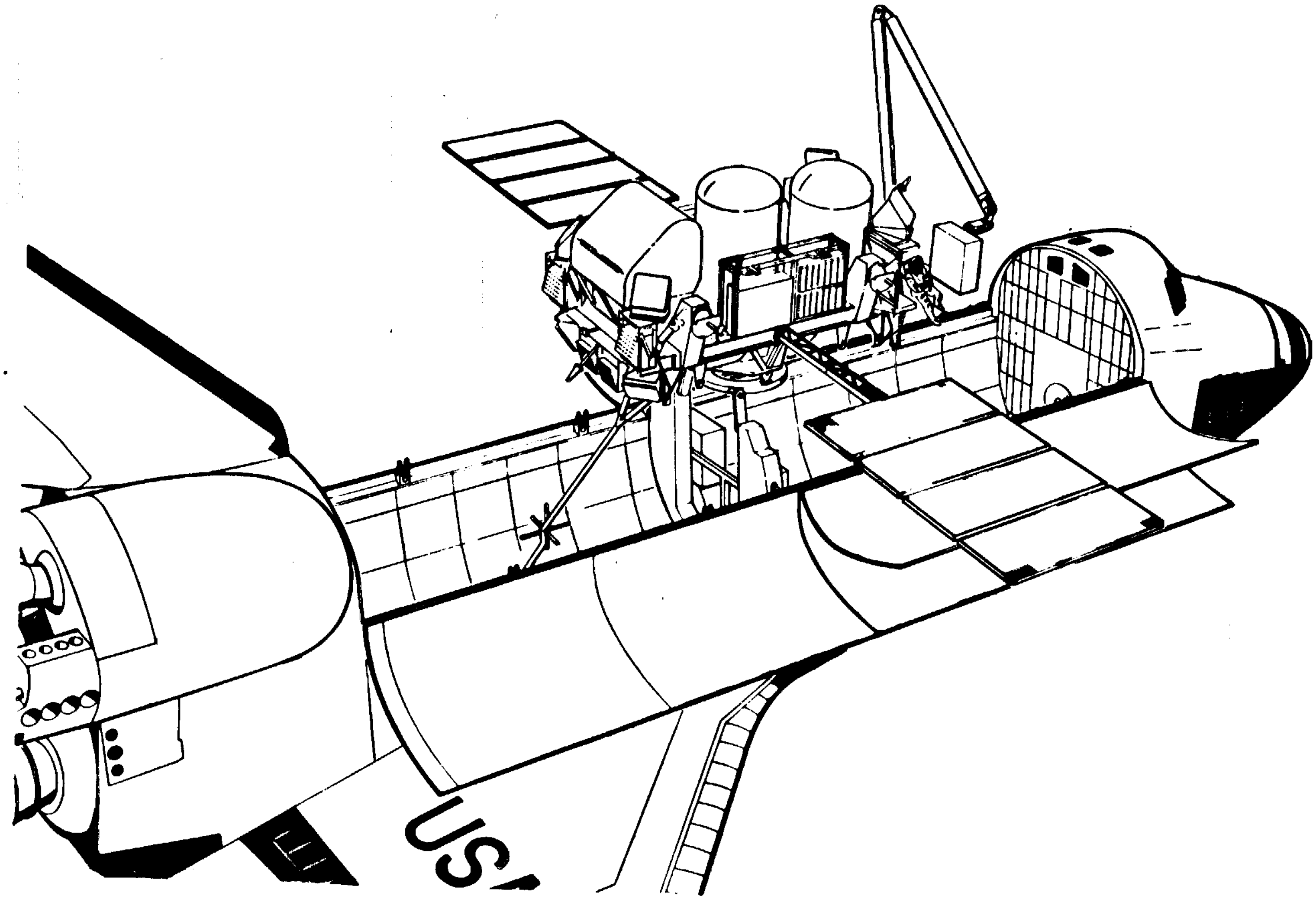
Solar Max Servicing

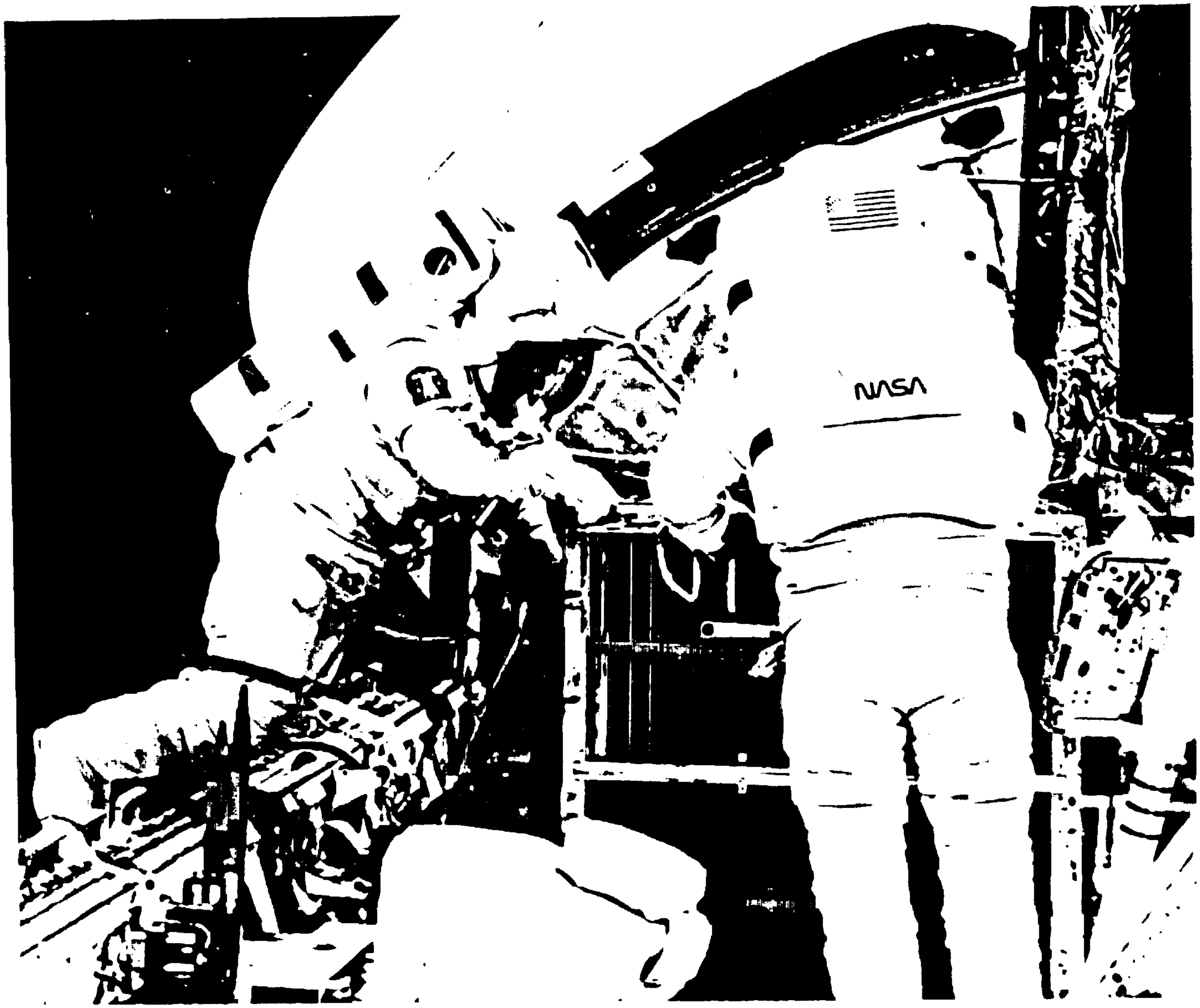


Repair Mission GRO ORU Changeout



TRW

Solar Max ORU Repair



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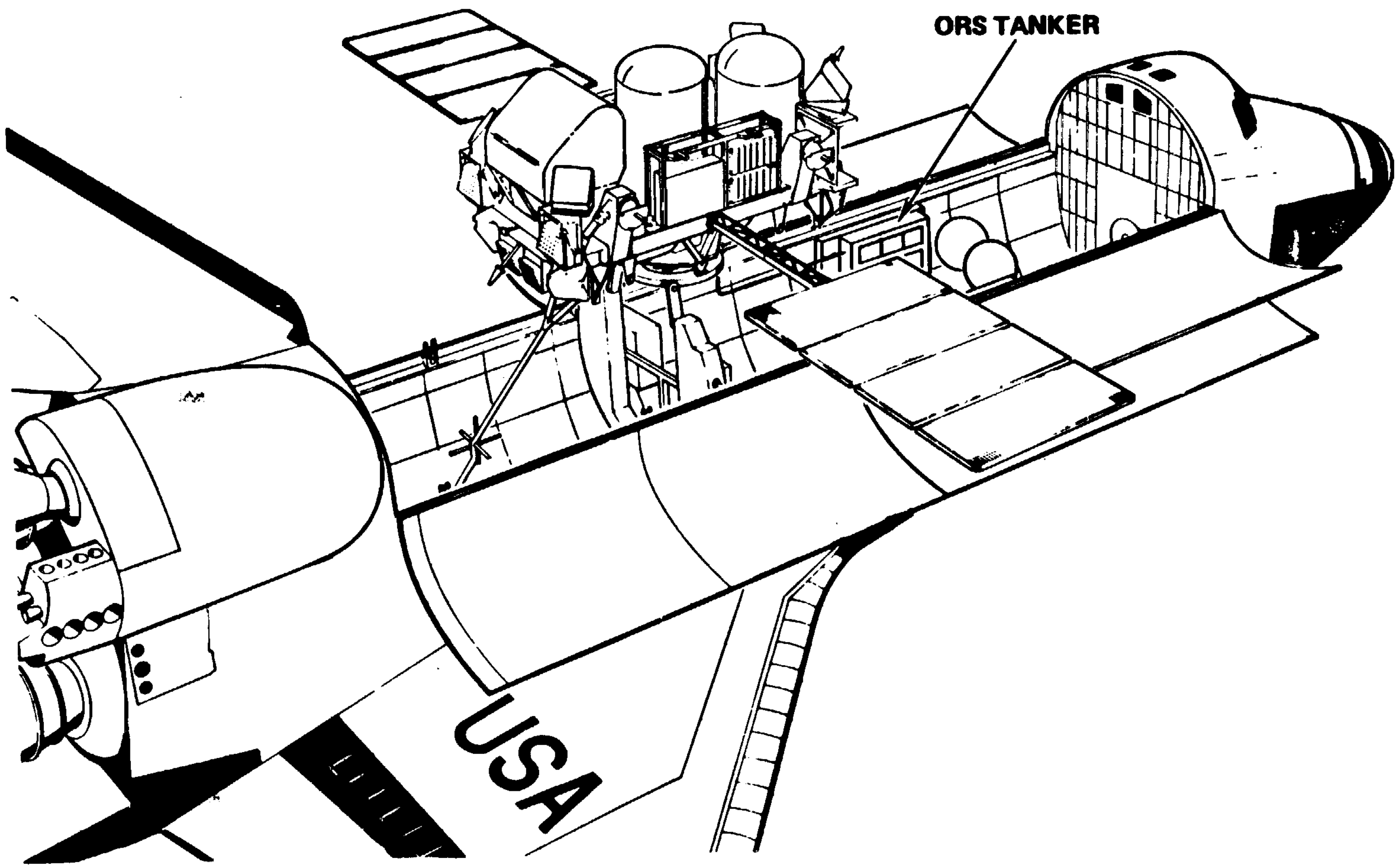
GRO Refueling

The GRO spacecraft will be the first on-orbit refuelable spacecraft. Current plans are to refuel the spacecraft after 2 years of operation. JSC is developing an on-orbit refueling system (first flight tests were on the October 1984 Shuttle flight). Although this first refueling mission does not involve OMV, it will demonstrate a key technology which together with OMV can enable satellite refueling in the future - initially by bringing satellites to the Shuttle or Space Station and later - by taking the refueling tanker to the satellite and performing the refueling operation remotely.

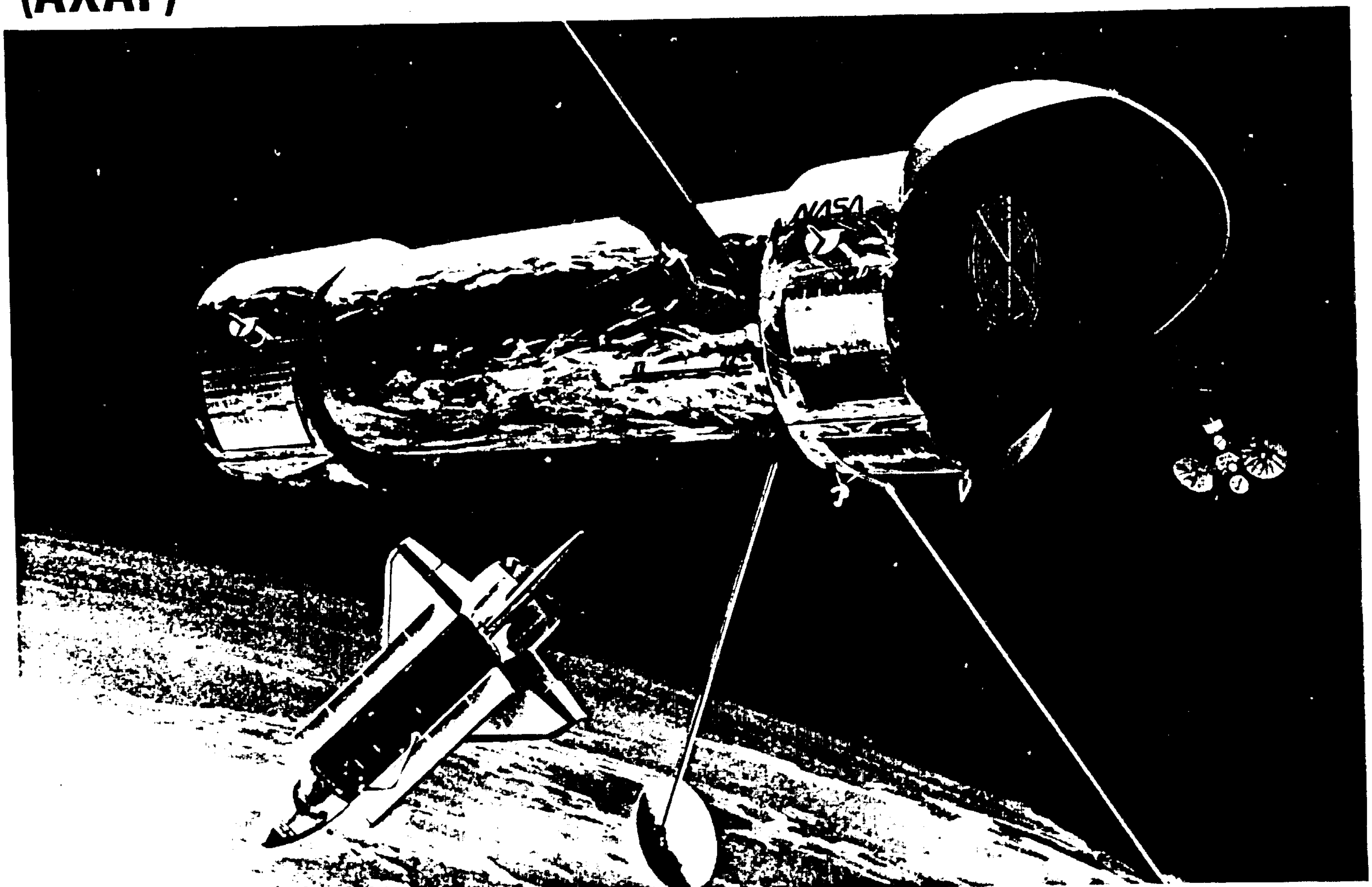
Refueling Mission Configuration: GRO On A' Cradle



Advanced X-Ray Astrophysics Facility (AXAF)

The AXAF is currently being studied at TRW on a Phase B contract for MSFC. This large spacecraft will be reboosted and as necessary returned for servicing to the Shuttle or Space Station using the OMV. As remote servicing technology is developed, kits will be added to the "front" of the OMV to allow module replacement remotely - at the satellite orbit. By using OMV AXAF can avoid the cost of integral propulsion.

The Advanced X-Ray Astrophysics Facility (AXAF)



TRW Space & Technology Group

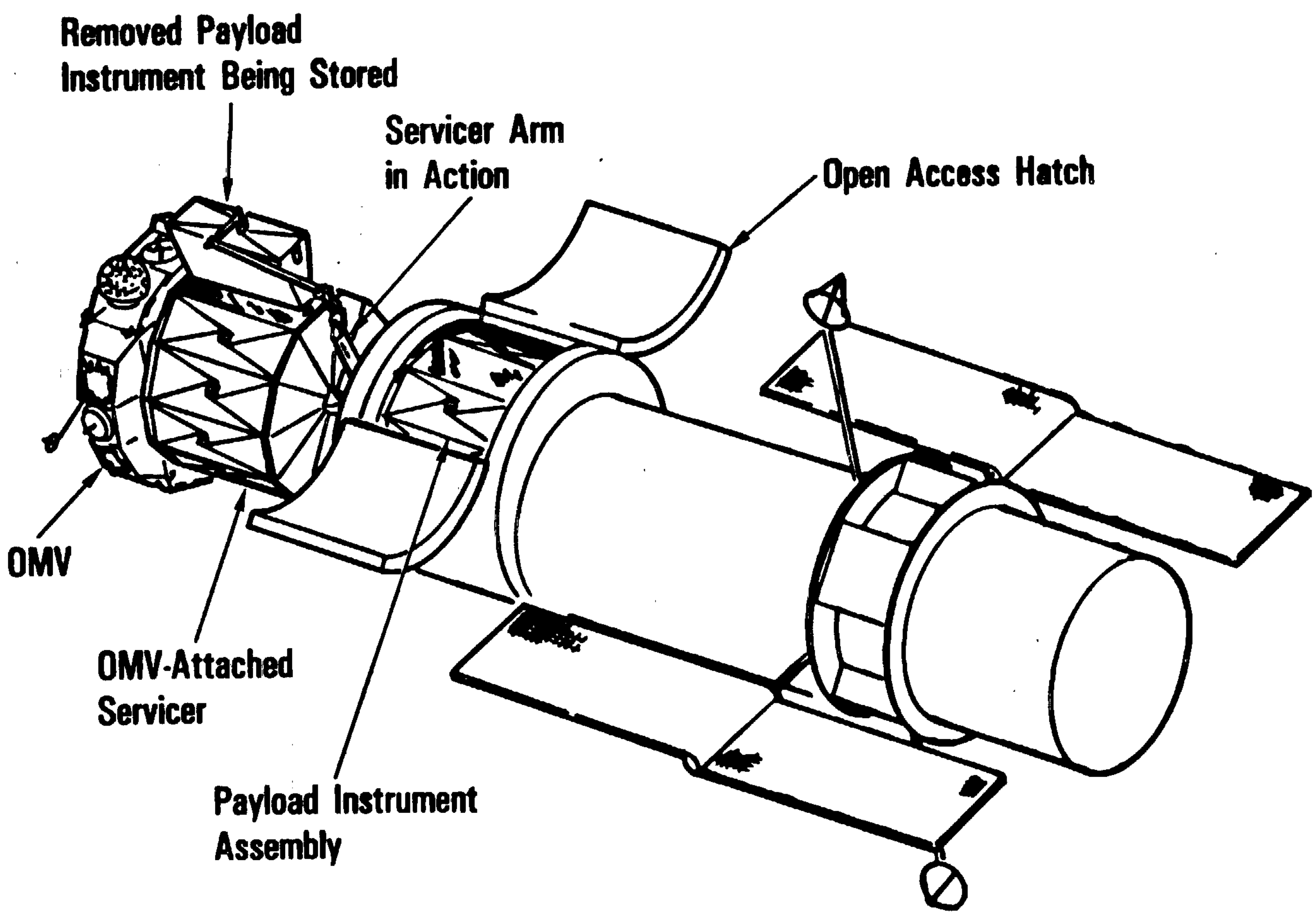
Payload Instrument Replacement on AXAF

A concept developed during the AXAF Phase A study involved an OMV equipped with a robotic servicer.

The removable payload units are focal plane instruments grouped in a cylindrical arrangement at the aft end of the observatory facility. In the design shown, payload instruments can be removed in radial (lateral) direction. To effect the changeout the servicer, berthed at the aft bulkhead, uses its manipulator arm to reach into the open access hatch, where it pulls out one instrument at a time. The instrument is shown in the process of being stored in an empty compartment of the servicer magazine. The next step for the servicer arm is to take a replacement unit from the magazine and insert it into the AXAF focal plane compartment just vacated.

AXAF servicing is similar to the instrument changeout process on the Space Telescope (ST) however, at this time, neither AXAF nor ST are actually scheduled for in-situ servicing, remote from the Shuttle or Space Station.

Payload Instrument Replacement on AXAF (Lateral Access)



Source: J. Turner, "Teleoperator Maneuvering System", Satellite Servicing Workshop, NASA/JSC, June 1982

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OMV: The Key to Satellite Servicing

In summary, OMV will extend man's reach and servicing capabilities beyond the limits of the Shuttle. Initially, the OMV will be a space tow truck designed to place and retrieve satellites. Servicing will be done at the Shuttle or Space Station. As robotics and thus space servicing become a reality, the OMV armed with a servicer will be able to perform the servicing operations "in situ" at the satellite orbit. This in-situ capability will be especially useful at GEO where man's presence is not likely for many years.

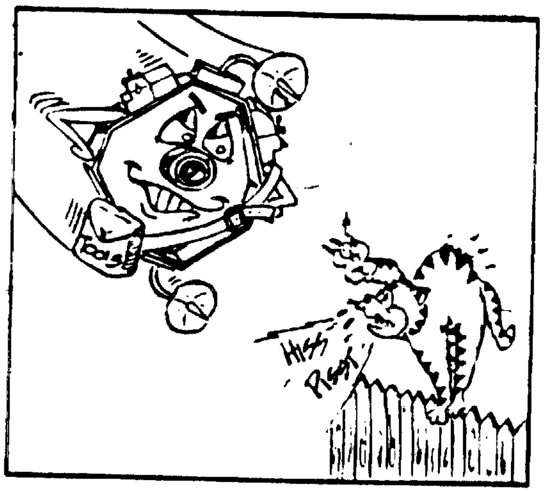
When a satellite is expired, the OMV will in essence haul it to the junk yard by controlled deorbit or bring it down to the Shuttle to be brought back as a museum piece.

OMV: THE KEY TO SATELLITE SERVICING

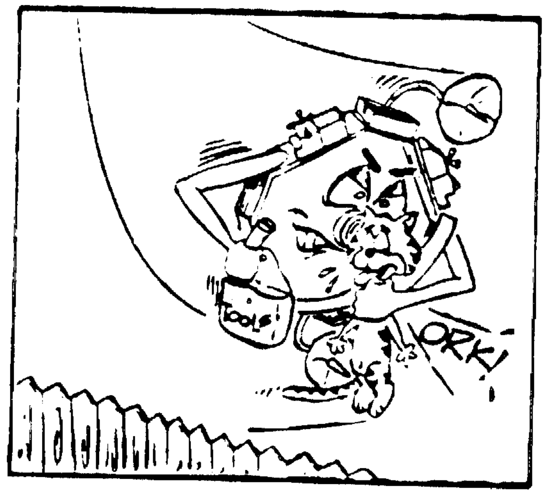
- OMV EXTENDS MAN'S REACH INTO SPACE BEYOND THE LIMITS OF THE SHUTTLE
- OMV PROVIDES CAPABILITY TO SERVICE SATELLITES FROM EITHER SHUTTLE OR SPACE STATION AND EVENTUALLY REMOTELY
  - REFUEL
  - MAINTAIN/SERVICE/CHANGEOUT
  - REBOOST
  - DEBOOST WHEN SERVICING IS NOT USEFUL

OMV Deboost Mission

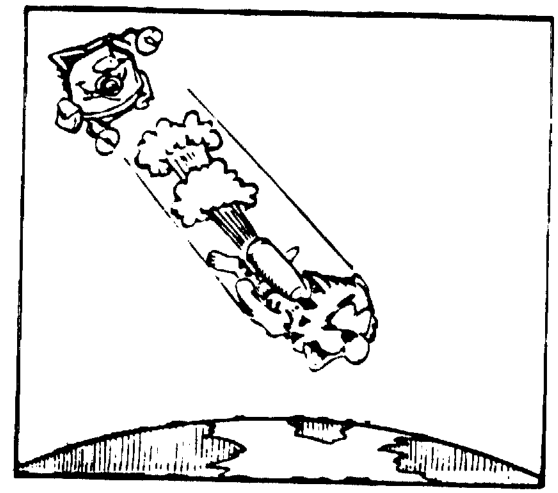
(Undesirable Debris Removal)



Rendezvous



Proximity Operations
and Docking



Deboost

F. Bergonz
Martin
Session #3
Presentation 4

OMV SERVICING CAPABILITY

ABSTRACT

The emphasis in this paper is on the increase in capability that becomes available when an integrated orbital servicing system is added to the basic OMV. The integrated orbital servicing system is described, including its docking mechanism, its storage rack and its manipulator arm. The capabilities described are for module exchange, fluid transfer and logistics support of space manufacturing facilities.

The benefits and reasons for developing a teleoperated servicing capability are presented. A development program starting with ground demonstrations and culminating in free flight operations is described.

TECHNICAL DISCUSSION

One of the future mission capabilities envisioned for the Orbital Maneuvering Vehicle is to provide servicing support of spacecraft at their operational orbits. Figure 1 depicts a few of the many mission capabilities projected for the Orbital Maneuvering Vehicle. Placement and retrieval will probably dominate the early missions. As the capability of OMV is demonstrated and verified, missions carrying experimental packages in subsatellite operations will be implemented. When the Space Station becomes operational, logistics support and viewing operations will become commonplace for OMV. The complexity associated with our large orbiting observatories will dictate periodic servicing supported by the Orbital Maneuvering Vehicle. Also

being considered as front-end kits for the OMV are an expendables resupply module and a capability for the recovery of tumbling satellites.

A future development associated with the Orbital Maneuvering Vehicle is evolution of a smart front-end kit which will provide remotely controlled on-orbit servicing of spacecraft designed to utilize this capability. On-orbit servicing functions may include modular exchange of subsystem and experiment packages; fluid transfer and resupply; replenishment of raw material modules and pickup of processed product modules. This servicing capability will be an extension and enhancement of the Extra Vehicular Activity (EVA) which has been recently developed and currently exists. The on-orbit servicing capability will extend the operating envelope over which servicing functions can be delivered.

The benefits of on-orbit servicing are listed in Figure 2. A servicing capability integrated with the mission capabilities of the orbital maneuvering vehicle will extend the access envelope for which servicing can be provided. Low earth orbit altitudes up to a 1,000 nautical miles will be within the reach of this servicing capability. The semi-automated teleoperational approach for delivering this servicing function will reduce the need for manned modules, will reduce the need for retrieval to the Space Station or the Orbiter for servicing, and will reduce the cost associated with extra vehicular activities. The on-orbit servicing approach will prove to be cost effective for many, but not all, satellite servicing functions. Retrieval and EVA will continue to be the most cost effective answer for many spacecraft. The criteria that are important in cost effectively selecting between these two approaches is discussed below.

When the need exists and the capability for transfer of the Oribital Maneuvering Vehicle to geosynchronous altitudes is developed, this service can also be provided for geosynchronous satellites. Representative programs which would be benefited by a servicing capability as part of the Orbital Maneuvering Vehicle program are spacecraft that have been delivered by the Space Transportation System, spacecraft that are operating in conjunction with the Space Station, Space Manufacturing Systems, a space-based laser system, other strategic defense initiative elements and communication satellites.

An extensive study of satellite servicing was conducted. The major elements of this study are depicted in Figure 3. The study consisted of comparing the cost effectiveness of expendable spacecraft programs vs. maintenance and repair after return and retrieval to earth vs. visiting spacecraft systems. Two subalternatives of visiting systems were EVA maintenance at the Orbiter vs. on-orbit servicing. The study results show that on-orbit maintenance is the most cost effective mode. The study also showed that the on-orbit servicers showed great versatility and could be utilized at the Orbiter or at a Space Station as well as a front-end kit on the Orbital Maneuvering Vehicle. The on-orbit servicer utilized a module exchange approach which greatly simplifies and reduces operational complexity of the repair process. It was found that most maintenance tasks were reduceable to a simple remove and replace operation. This module exchange approach implies specifically designed spacecraft, however, the design constraints, impacts, and penalties were not considered serious.

The servicer and storage rack design, which resulted from this study, is shown in Figure 4. The storage rack consisted of a tubular truss design that

mounts on the front face of the Orbital Maneuvering Vehicle. Modules of various sizes and shapes can be arranged on the storage rack. The interface mechanism for attachment of the modules to the storage rack is the same mechanism that is utilized for attaching the module to the operational spacecraft. The servicer utilizes a docking probe for making a firm and hard mechanical interface with the operational spacecraft. A particular docking probe design is depicted in the picture, but the design can vary so that it is compatible with the spacecraft to be serviced. A pivoting arm form of servicer mechanism is shown on the servicer and is used to remove modules from the operational spacecraft and place them on the storage rack. The arm is also utilized for the module replace function. An end effector that is compatible with the module attachment mechanism is shown. This end effector contains both a grip capability and a power takeoff capability for loosening and tightening the module fasteners. The servicer design and interface requirements are compatible with the Orbital Maneuvering Vehicle payload support capability.

This design was further pursued in terms of an engineering test unit that was built and delivered to the Marshall Space Flight Center. The engineering test unit shown in Figure 5 includes a mockup of an operational spacecraft, a breadboard of the storage rack, and an operational servicer arm mechanism that is utilized to transfer modules between the spacecraft and the storage rack. A control panel was also included as part of the engineering test unit. Operational attachment mechanisms for modules were included as part of this development. The servicer arm is capable of being moved to a module, making a firm mechanical interface with the module, releasing the module fastener, transporting the module to the location for its placement, tightening the

fastener to engage the module in the surrounding structure, demating the end effector from the module and moving the arm to a neutral position. This system has been operated several hundred times to demonstrate its repeatability and reliability. This system is operational at the Marshall Space Flight Center today and continues to be demonstrated on a routine basis.

As noted above, on-orbit servicing will prove to be a cost effective approach for many but not all spacecraft programs. The criteria that must be used in evaluating the applicability of spacecraft on-orbit servicing to an individual program are identified in Figure 6. The spacecraft cost is an important fundamental parameter. If the program utilizes a very inexpensive approach, then servicing may not prove to be a cost effective technique for repair or upgrade of the satellites in the program. The number of spacecraft in orbit for a given program is also an important factor. The previous studies show that servicing is cost effective for programs utilizing multiple identical spacecraft. The desired program life as compared to the mean time between failure of the individual satellites in a program is an important relationship in determining the cost effectiveness of on-orbit servicing. If there is a program requirement or desire to upgrade the capability of the satellites in the program during their lifetime, then on-orbit accomplishment of this capability will ususally prove to be the most cost effective technique. Expendables replenishment can also be a cost effective function for servicing. Usually propellant resupply itself does not prove to be cost effective for on-orbit servicing. Supplying a greater initial quantity of propellants is usually a more cost effective approach. However, when propellant resupply is combined with repair or upgrading, it does become a cost effective function. On-orbit maintainability will require at least a certain degree of component and subsystem standardization from a modularity point of view.

The parameters that must be evaluated to determine cost effectiveness of on-orbit repair and maintenance are shown in Figure 7. The studies previously performed indicated that spacecraft design costs when servicibility is included increase by approximately 5%. Also important to the cost effectiveness of servicing are the initial launch costs for the spacecraft program, the spares procurement for the on-orbit servicing case vs. non-servicing, the spares maintenance costs, and the repair transportation costs. Servicer system development has been estimated to be on the order of 50 million dollars total. It is envisioned that this cost would be prorated across a large number of programs.

The results of our previous study are shown in Figure 8 and conclude that on-orbit maintenance is the most cost effective approach for many programs. The penalties associated with design for servicing are acceptable. On-orbit maintenance saves large percentages of program costs for many typesof satellite programs. Because of the cost effectiveness that an on-orbit servicing capability offers, it is important that a development program continue in order to assure potential users that a servicing capability will be available. The development program scope is shown in Figure 9. The three major activities involve a series of ground demonstrations followed by Orbiter cargo-bay demonstrations which will be followed by a full free-flight verification of the on-orbit servicing capability. The ground demonstrations will utilize the existing engineering test unit servicer mechanism. The cargo-bay demonstration will utilize a protoflight quality servicer with the free-flight verification operations utilizing the operational servicer system. The objectives of each of these phases of development are shown in Figure 10. The ground demonstrations will concentrate on technology

development and obtaining an understanding of the operations involved. The ground tests will utilize a variety of control modes for the servicer system. Several different types of modules will be utilized in the tests. Different interface mechanisms will be evaluated and various trajectories for the servicing arm will be evaluated. Also hose management for applicability to replenishment of fluids will be tested. These evaluations are planned to be completed in 1986.

The objective of the cargo-bay demonstrations will be to confirm ground tests and increase confidence in the on-orbit capability of the servicing system. Emphasis will be placed on demonstrations of changeout of multi-mission modular satellite modules as well as generic modules. Transfer of fluids will also be performed in the cargo-bay tests. Control is envisioned at the aft flight deck of the Orbiter. These demonstrations and evaluations are planned to be completed by 1989. Free-flight verification will require the development and fabrication of an operational servicer compatible with zero-g and free-flight operations. OMV will be utilized as the carrier vehicle for these free-flight operations. A second spacecraft, similar to the SPAS 01 capability will be also utilized as part of the free-flight verification process. Control for these operations is envisioned to eminate from a ground control station. These evaluations should be completed by 1992 to be compatible with the future requirements of the Space Station and the Space Transportation System servicing capabilities.

CONCLUSIONS

An artist's concept of the operational servicer is shown in Figure 11. We believe that development of such a servicer and its associated capability will

greatly enhance the cost effectiveness and utility of both our national Space Transportation System and the Space Station. The capability to provide the type of servicing that is currently delivered by EVA astronauts will be extended throughout the low earth orbit operational range when the on-orbit servicer is developed. This extension of servicing capability will greatly increase the number of potential users of orbital servicing. The resultant effect will be a significant reduction in overall operational costs for many spacecraft and satellite programs. The capability developed in the on-orbit servicer will also provide a useful operational technique which can be used in Space Station servicing bays as well as in the Orbiter's cargo bay. We look forward to supporting NASA in the development of this most important future space technological capability.

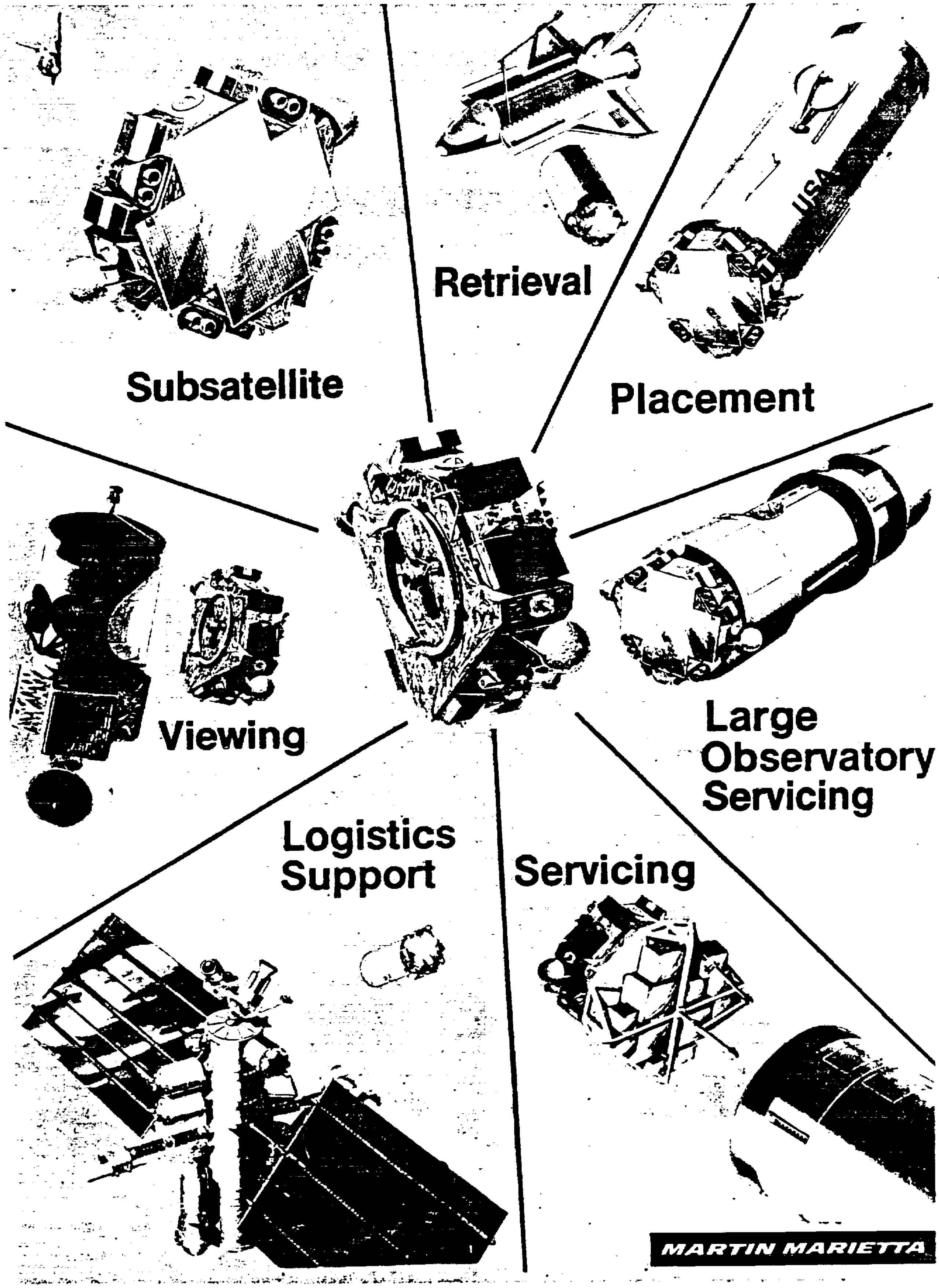


FIGURE 1 - OMV MISSIONS

FIGURE 2: REMOTE SERVICING CAPABILITY BENEFITS

o BASIS
- EXTEND ORBITAL ACCESS
- REDUCE NEED FOR MANNED MODULES
- REDUCE EVA RELATED COSTS
- ASSIST EXTENSION OF TERRESTRIAL AUTOMATION TO SPACE

o REPRESENTATIVE ORBITS
- LOW EARTH ORBIT (LEO)
  (INTERMEDIATE ALTITUDE AND INCLINATION CHANGES)
- GEOSYNCHRONOUS EARTH ORBIT (GEO)
  (USING AN ORBITAL TRANSFER VEHICLE)

o REPRESENTATIVE PROGRAMS
- SPACE TRANSPORTATION SYSTEM
- SPACE STATION
- OBSERVATORIES AND FACILITIES
- SPACE BASED LASER
- COMMUNICATIONS SATELLITES

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FIGURE 3
INTEGRATED ORBITAL SERVICING STUDY - OVERVIEW

MAINTENANCE APPROACHES CONSIDERED

- EXPENDABLE
- ON-GROUND
- VISITING SYSTEMS
  - EVA
  - SRMS
  - ON-ORBIT SERVICERS
    - PIVOTING ARM
    - GENERAL PURPOSE MANIPULATOR

CONCEPTS

SELECTED

EXPENDABLE — GROUND REFURBISHABLE — ON-ORBIT MAINTENANCE — MODES

- ON-ORBIT MAINTENANCE IS MOST COST EFFECTIVE MODE
- ON-ORBIT SERVICERS ARE MORE VERSATILE
  - USEFUL AT ORBITER, AT SPACE STATION, ON OMV, AT GEO WITH APPROPRIATE CARRIER VEHICLE
- PIVOTING ARM USES MODULE EXCHANGE APPROACH
  - EMPHASIZES OPERATIONAL SIMPLICITY
  - MOST MAINTENANCE TASKS REDUCIBLE TO REMOVE AND REPLACE
- MODULE EXCHANGE IMPLIES SPECIALLY DESIGNED SPACECRAFT
  - CONSTRAINTS AND PENALTIES NOT SERIOUS

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ON-ORBIT SERVICER - FLIGHT UNIT

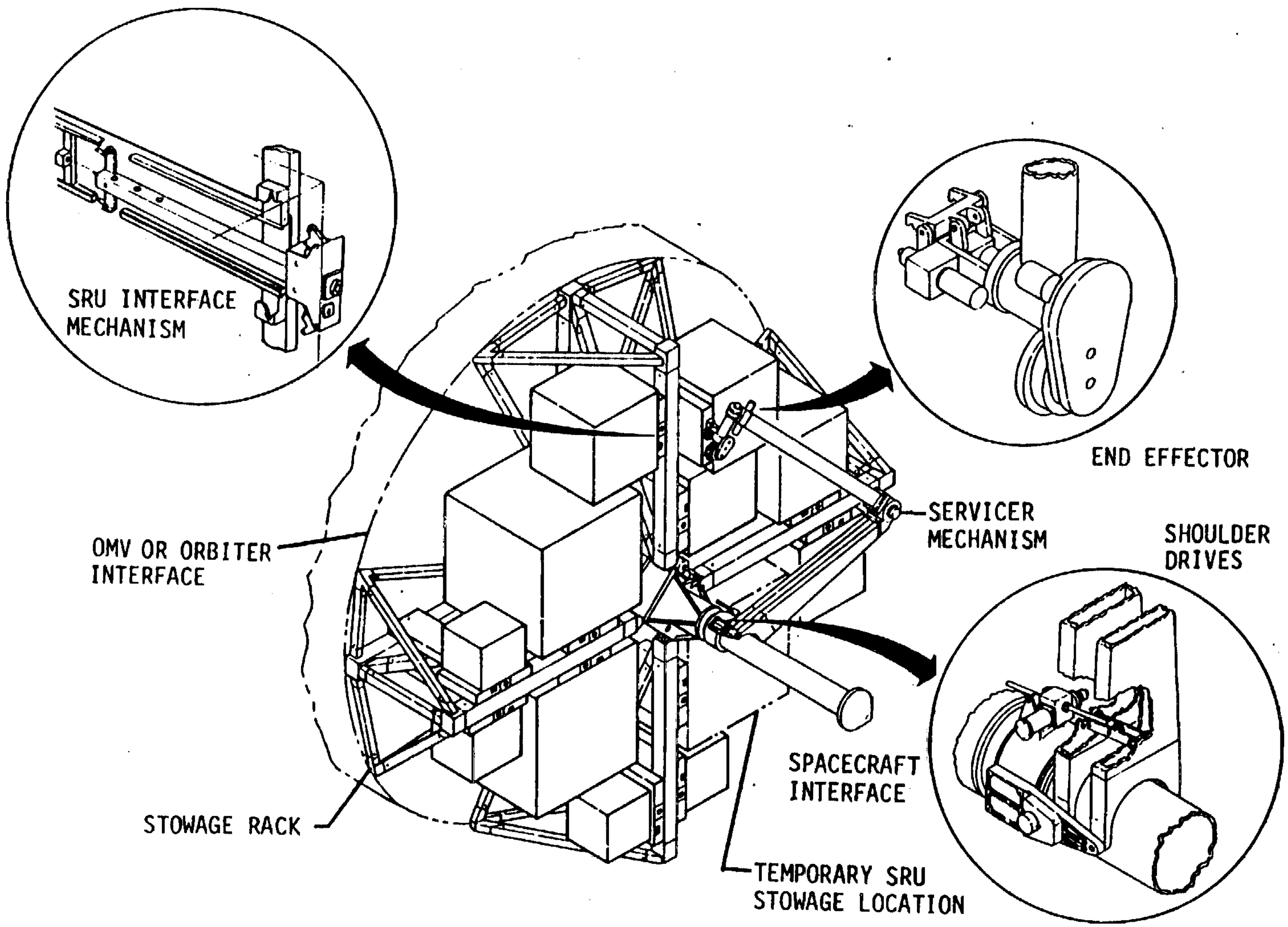
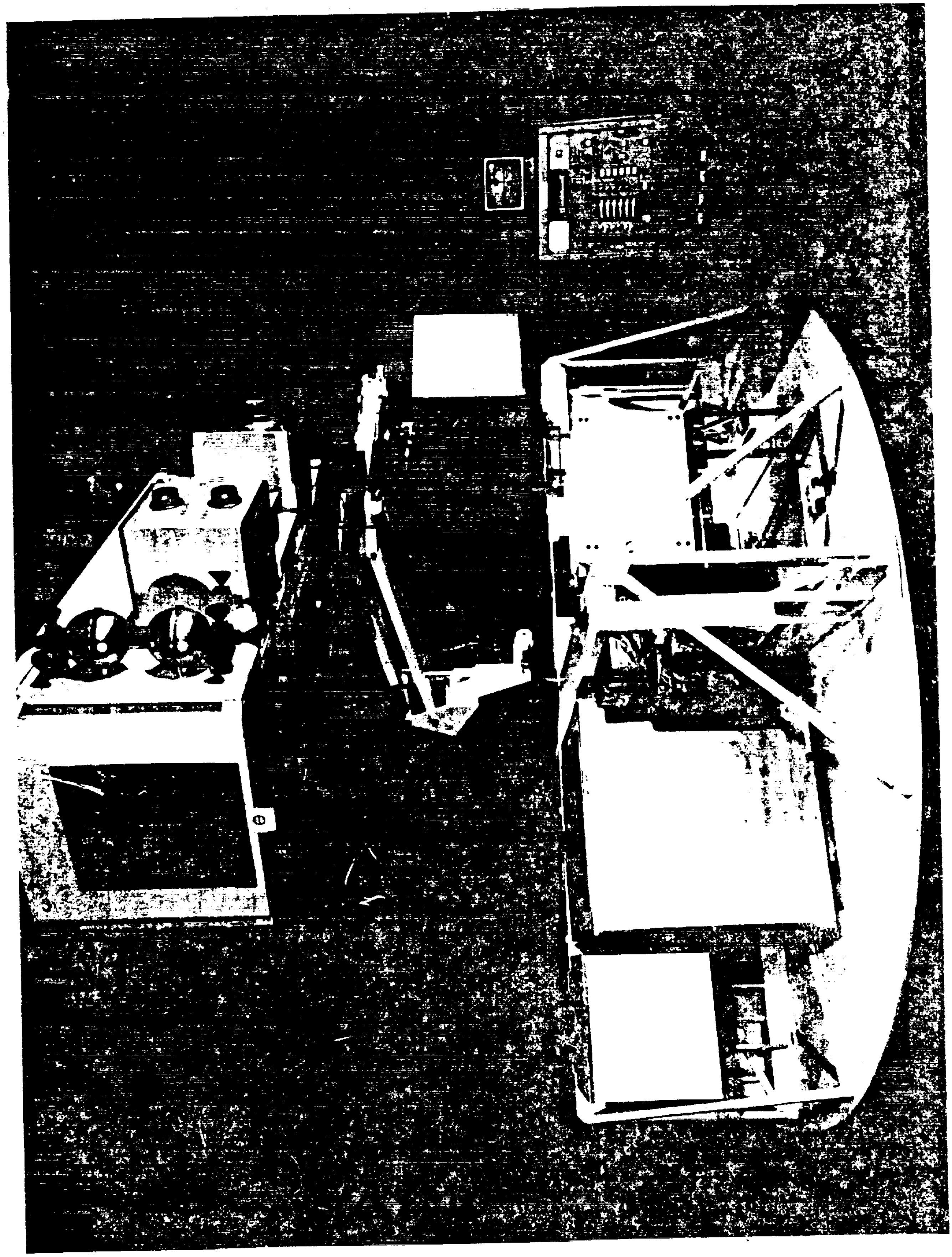


FIGURE 4



MAINTAINABILITY CRITERIA FIGURE 6

- SPACECRAFT COST
- NUMBER OF SPACECRAFT ON ORBIT
- DESIRED LIFETIME
- MEAN TIME TO FAILURE
- EXPECTATION OF UPGRADING
- EXPENDABLES CONSUMPTION
- COMPONENT/SUBSYSTEM STANDARDIZATION

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KEY COST ASPECTS FIGURE 7

- SPACECRAFT DESIGN FOR SERVICEABILITY $\simeq$ 5% INCREASE
- INITIAL LAUNCH COSTS
- SPARES PROCUREMENT
- SPARES MAINTENANCE
- TRANSPORTATION COSTS
- SERVICER SYSTEM DEVELOPMENT - $50M
- OPERATIONS COSTS

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IOSS STUDY RESULTS FIGURE 8

ON-ORBIT MAINTENANCE IS THE MOST COST-EFFECTIVE MODE

SPACECRAFT CAN BE DESIGNED TO BE SERVICEABLE WITH ACCEPTABLE DESIGN, WEIGHT, VOLUME, AND COST EFFECTS

THE PIVOTING ARM ON-ORBIT SERVICER WAS SELECTED AND A PRELIMINARY DESIGN PREPARED

USE OF ON-ORBIT MAINTENANCE CAN SAVE 36 PERCENT OVER THE EXPENDABLE MODE OR 21 PERCENT OVER THE GROUND REFURBISHABLE MODE

FOR A 50 PERCENT MISSION MODEL, ON-ORBIT MAINTENANCE SYSTEM IS COMPATIBLE WITH MANY SPACECRAFT PROGRAMS AND IS RECOMMENDED

A SINGLE DEVELOPMENT OF AN ON-ORBIT SERVICER MAINTENANCE SYSTEM IS COMPATIBLE WITH MANY SPACECRAFT PROGRAMS AND IS RECOMMENDED

ORBITAL MAINTENANCE DOES NOT HAVE ANY SIGNIFICANT IMPACT ON THE SPACE TRANSPORTATION SYSTEM

USER NEED GUARANTEES THAT SERVICING WILL BE AVAILABLE AND ASSURANCES THAT IT WILL BE COST EFFECTIVE

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FIGURE 9: REMOTE SERVICING DEVELOPMENT PROGRAM

- o THREE INTEGRATED ACTIVITIES
  - GROUND DEMONSTRATIONS: ENGINEERING TEST UNIT SERVICER
  - CARGO-BAY DEMONSTRATIONS: PROTOFLIGHT QUALITY SERVICER
  - FREE-FLIGHT VERIFICATION: OPERATIONAL QUALITY SERVICER
- o BASED ON PROVEN INTEGRATED ORBITAL SERVICING STUDY DESIGNS AND TEST HARDWARE
- o EMPHASIS ON EXCHANGE OF MULTI-MISSION MODULAR SPACECRAFT MODULES
- o INCLUSION OF GENERIC MODULE EXCHANGE
- o COORDINATED WITH EXPENDABLES RESUPPLY DEVELOPMENT

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FIGURE 10: REMOTE SERVICING DEVELOPMENT CHARACTERISTICS

- o GROUND DEMONSTRATIONS
  - TECHNOLOGY AND OPERATIONS INVESTIGATIONS
  - VARIETY OF CONTROL MODES, MODULES, INTERFACE MECHANISMS, AND TRAJECTORIES
  - ADD RESUPPLY HOSE MANAGEMENT
  - COMPLETE 1986
- o CARGO-BAY DEMONSTRATIONS
  - CONFIRM GROUND TESTS AND INCREASE USER CONFIDENCE
  - EXCHANGE MMS AND GENERIC MODULES
  - TRANSFER REFEREE FLUIDS
  - CONTROL FROM ORBITER AFT FLIGHT DECK
  - COMPLETE 1989
- o FREE-FLIGHT VERIFICATION
  - EXISTENCE OF AN OPERATIONAL SERVICER SUITABLE FOR USE WITH THE STS AND THE SPACE STATION
  - OMV AS SERVICER CARRIER VEHICLE
  - RENTED SPACECRAFT AS SERVICED VEHICLE
  - CONTROL FROM GROUND
  - COMPLETE 1992

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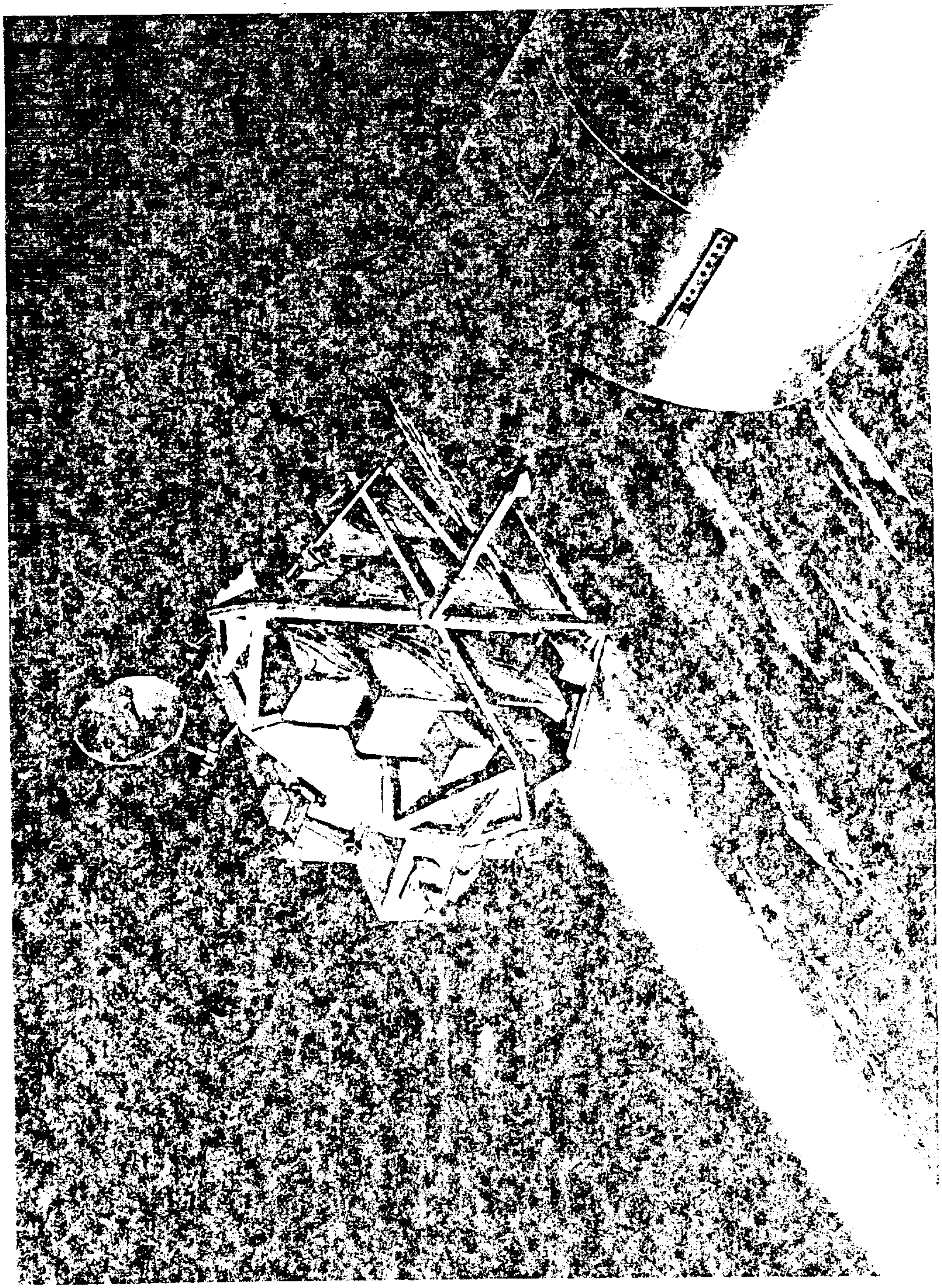

The Orbital Maneuvering Vehicle

20 February 1985

Rendezvous and Proximity Operations Workshop

NASA-JSC

OUTLINE

The preceeding two speakers in this session addressed the OMV primarily in the context of services which the OMV will provide. The focus of this presentation is the specific OMV design requirements which should be of interest to the users of these services. The requirements core of this material is preceeded by several application illustrations of general interest.

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C-5.

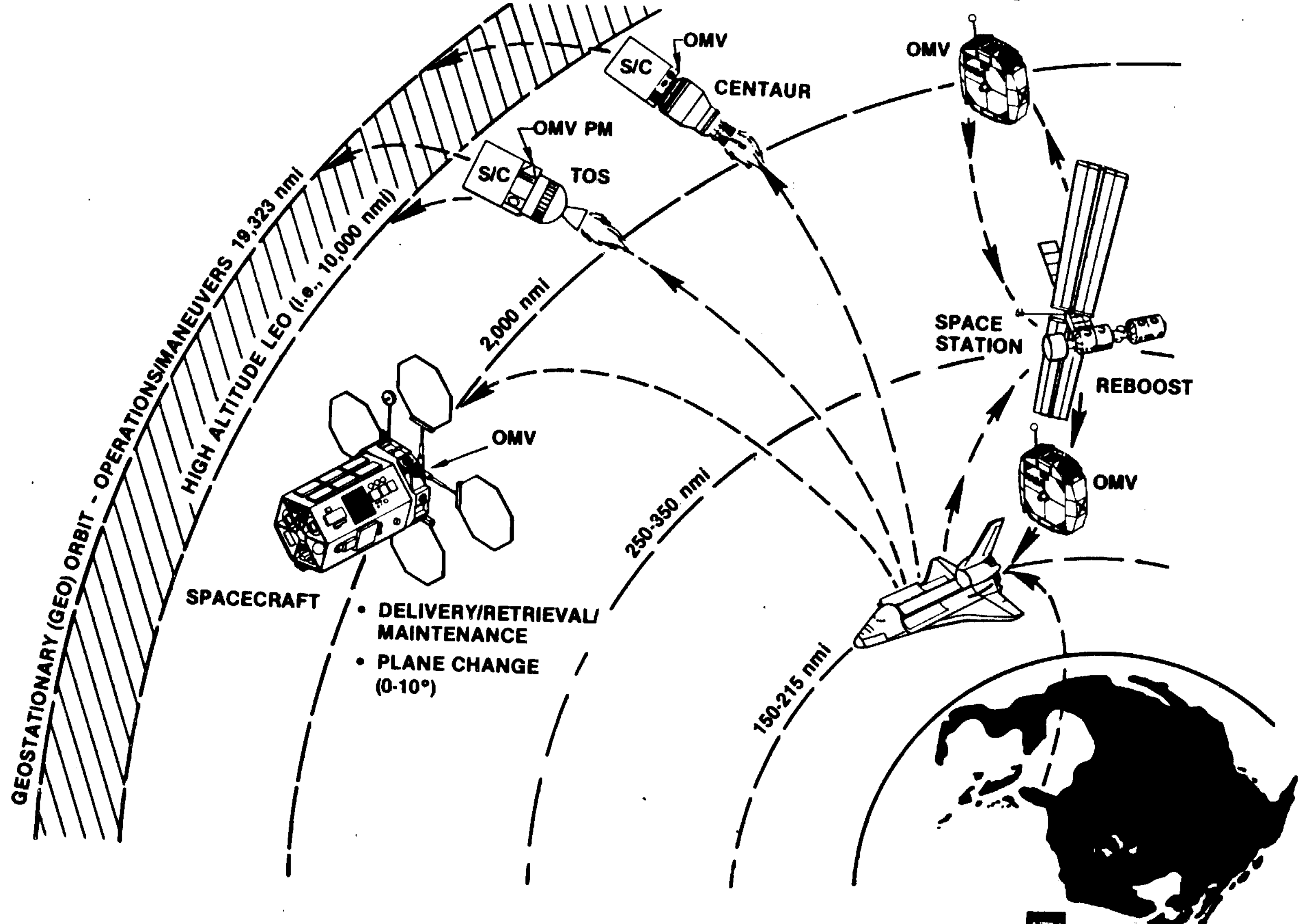
OUTLINE

- OMV APPLICATIONS OVERVIEW
- REQUIREMENTS SUMMARY

OMV APPLICATIONS OVERVIEW

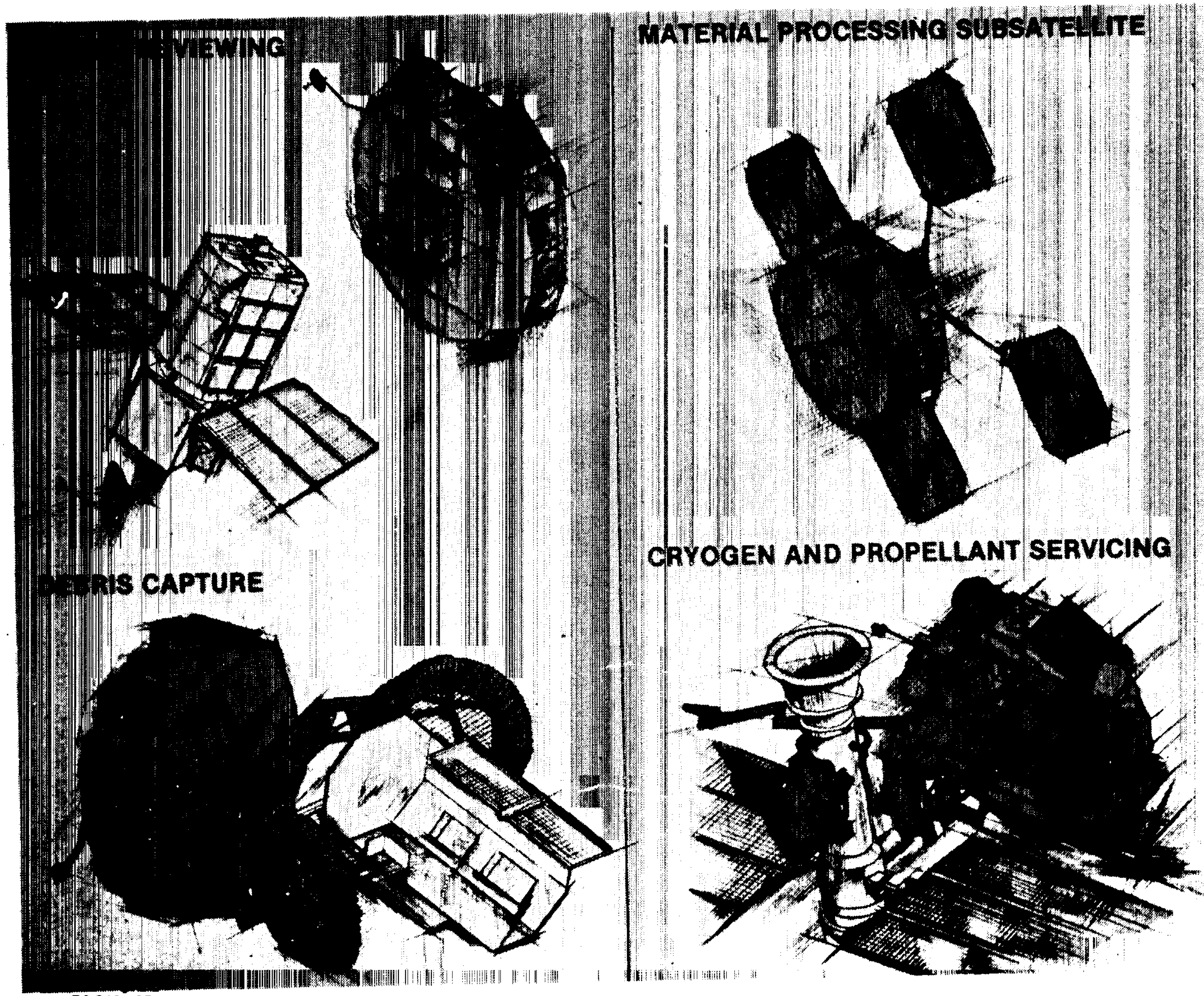
The illustration on the opposing page shows an overview of OMV applications which encompasses the operating regimes for applications cited by the preceeding OMV speakers. As the requirements unfold we shall see that NASA-MSFC has defined the basic capability OMV to be used in Low Earth Orbit (LEO) operations with the exception of the derivative propulsion module (PM) which is utilized with the Transfer Orbit Stage (TOS), the Centaur, or subsequent Orbital Transfer Vehicles (OTV) to reach Geostationary (GEO) orbits.

OMV APPLICATIONS OVERVIEW



LTV Aerospace and Defense
Vought Missiles and
Advanced Programs Division

OMV SERVICES



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OMV Rendezvous with AXAF

LTV Vought

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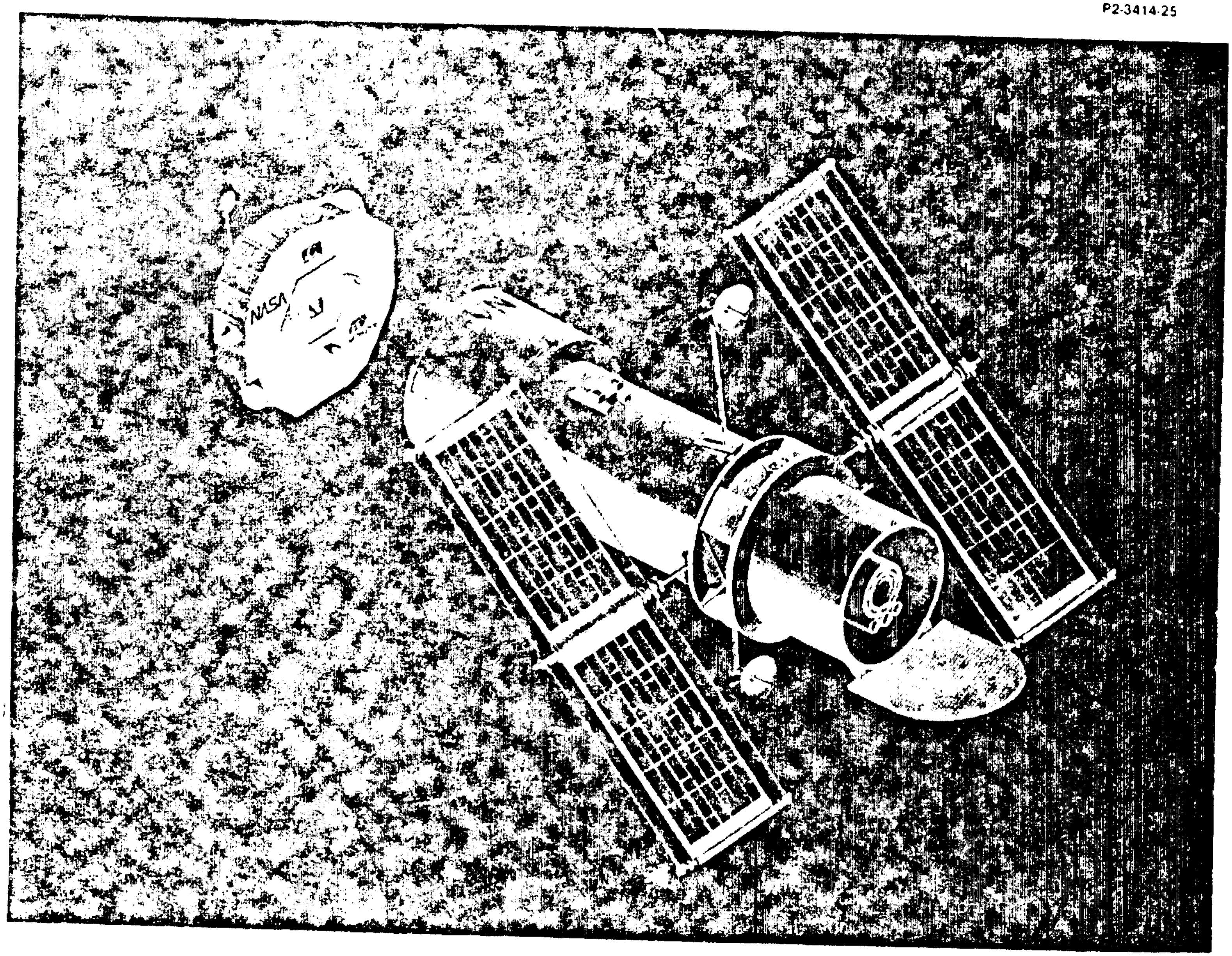
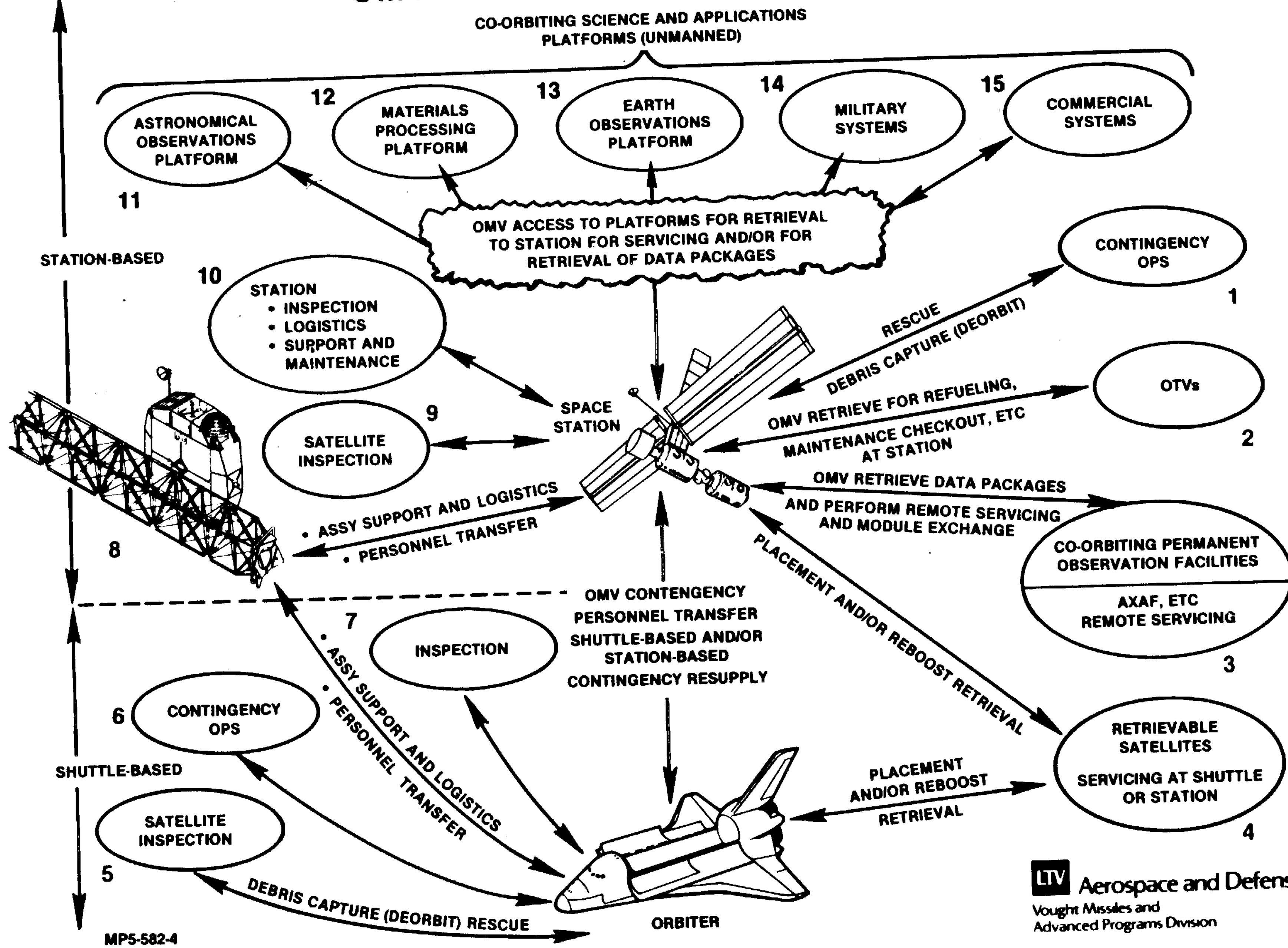


OMV IN THE SPACE STATION ERA



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DESIGN AND PERFORMANCE REQUIREMENTS

The Design and Performance Requirements as defined by NASA-MSFC are reviewed as the focus of this presentation. As shown on the opposing page, the four major elements of the OMV system are addressed initially, followed by five areas of requirements which provide increasing insight into the OMV capabilities.

The OMV Preliminary Design studies are being conducted under the Office of Management and Budget Circular A-109 protocol which provides that all three competing contractors develop derived requirements and designs in response to NASA broad category-top level requirements with no information exchange among the contractors.

The three contractor studies have been underway since September, 1984 with requirements reviews conducted at NASA-MSFC in November, 1984. An updated requirements document was subsequently issued by NASA-MSFC in January, 1985. The information presented herein is abstracted from that requirements document. Contractor trade studies and preliminary designs in response to those requirements are presently underway.

Design and Performance Requirements

Orbital Maneuvering Vehicle
Airborne Support Equipment
Ground Support Equipment
Control Stations

Operational Modes
Missions
Operations
Interfaces
Subsystems

DESIGN AND PERFORMANCE REQUIREMENTS

Selected overall requirements of the OMV are summarized on the opposing chart. The requirement for a propulsion module derivative is the only Geostationary (GEO) orbit operation requirement for the basic OMV. The Future Capability OMV, which is referred to where applicable throughout this requirements summary, will be configured for long duration missions in both low earth orbit (LEO) and GEO.

The many illustrations of OMV services shown previously may be achieved by the use of equipment kits consisting of strap-on/bolt-on propulsion units, docking/manipulator mechanisms, servicing kits, tanker modules, and refueling kits. The OMV propellant loading may be provided by either integral, integral plus kittable tankage, or on-orbit refueling.

The control philosophy for the OMV is summarized on the opposing chart. The distance for the operating zone around the Station beyond which the OMV will be under ground control has not yet been determined. The rendezvous/docking operations using real-time television must account for the communications time delays inherent in a video link through the Tracking and Data Relay Satellite System for LEO operations and the ground network for GEO operations. The location of the OMV Ground Control Station (GCS) will be determined by NASA rather than the OMV contractor.

The on-orbit repair and maintenance of other vehicles which is facilitated by the OMV extends to requirements for definition of Orbital Replacement Units (ORUs) for the OMV as well. The maintenance events at the ORU level which support the 10-year design life are anticipated for both STS and Space Station operations. The ORU's may be refurbished if shown to be cost effective. Just as the OMV facilitates consumables resupply for other vehicles, it must also be designed for on-orbit resupply of its consumables.

The Future Capability OMV kitting philosophy is reflected throughout all OMV requirements.

Design and Performance Requirements

ORBITAL MANEUVERING VEHICLE – LEO

- Reusable-Operating out of Orbiter or Station
- Designed to Permit Propulsion Module Derivative (LEO/GEO)
- Propellants Integral, Kitted Tanks, or Refueled

CONTROL

- *From Ground Control Station (GCS) for Operation out of Orbiter and Beyond Specified Zone from Station*
- *From Station Within Specified Zone*
- *By Automatic Flight Except Terminal Rendezvous/Docking (R/D)*
- *R/D Control from GCS Using TV and Sensors As Required*

ON-ORBIT REPAIR/MAINTENANCE

- *At Orbital Replacement Unit Level*
- *Consider EVA and Remote Operations*

DESIGN LIFE

- *Ten Years with ORU Maintenance*
- *Multiple Reuse Between Maintenance Events*

CONSUMABLES RESUPPLY

- *Accommodate On-Orbit Replacement*
- *Develop Operational Concepts and Interface Requirements*

FUTURE CAPABILITY OMV

- Provide by Scarring Kitting and/or Upgrading
- Long Duration Missions in Both LEO and GEO

DESIGN AND PERFORMANCE REQUIREMENTS

The Airborne Support Equipment (ASE) includes all unique equipment and interface devices that remain aboard the STS and/or the Space Station to support the OMV during all phases of the mission. NASA-MSFC requires a philosophy of minimum electrical interfaces and ASE to operate in the stowed mode, deploy, deactivate, and restow the OMV at the STS Orbiter and the Space Station. Interfaces to provide the OMV state vector/attitude updates and to remotely disconnect/reconnect electrical fluids is on an as required basis. The OMV is required to be removed/reinstalled with the Orbiter or Station manipulators. Requirements are provided for maintenance/servicing equipment at the Station but not at the Orbiter. Any ASE at the Orbiter is provided by the OMV program whereas ASE at the Station is provided by the Station program.

Design and Performance Requirements

AIRBORNE SUPPORT EQUIPMENT - MINIMUM INTERFACES

Orbiter - Provided by the OMV Program

Electrical Provides State Vector/Attitude Updates as Required
Mechanical Provides Removal/Reinstallation with the Orbiter RMS
Remote Disconnect/Reconnect of Electrical/Fluids as Required

Station - Provided by the Station Program

Electrical Same as Orbiter
Mechanical Provides Removal/Reinstallation with Station Manipulator
Remote Disconnect/Reconnect Same as Orbiter
Maintenance/Servicing

- Equipment to Hold/Manipulate OMV
- Stowage and Robotic and/or Manned Changeout of ORU's
- Consumable Carriers with Control/Monitor of Transfers

DESIGN AND PERFORMANCE REQUIREMENTS

Ground Support Equipment (GSE) which includes Electrical Ground Support Equipment (EGSE) and Mechani-
cal Ground Support Equipment (MGSE) will support the systems testing, interface verification, verification
assembly, integration, launch, and refurbishment of the OMV and its associated Airborne Support Equipment
(ASE). The GSE must be compatible with either vertical or horizontal cargo bay installation and/or removal
options. Two categories of electrical GSE are required as shown on the opposing chart. The OMV Mechanical
Ground Support Equipment (MGSE) will support OMV handling, maintenance equipment, access stands, alignment
equipment, transportation, purging, and cooling.

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Design and Performance Requirements

GROUND SUPPORT EQUIPMENT

Supports Testing, Verification, Launch and Refurbishment of OMV/ASE
Compatible with Vertical or Horizontal Orbiter Installation/Removal

Electrical

- Flight Black Box Verification
- Integrated OMV Verification with Centralized Control/Monitor

Mechanical

- OMV Handling, Maintenance, Alignment, Transportation
- Expendables Handling

DESIGN AND PERFORMANCE REQUIREMENTS

The OMV shall be controlled by the OMV Ground Control Station (GCS) and/or the Space Station Control Station. An OMV GCS is required to control and support the OMV mission operations. This GCS will provide the capability to command the OMV, to provide pilot to vehicle interactive controls, to process and display data, to house engineering support, and to support engineering analysis. The commands, control and data retrieval will be via the Spaceflight Tracking and Data Network (STDN) interface.

The computer support in the GCS is required to be standard commercial equipment to provide the functions summarized on the opposing chart. Real-time and near real-time data retrieval calibration and display are required. Specific requirements are provided for GCS consoles and conference work areas to support mission operations and coordination functions.

The GCS is required to support training of the mission operations organization. The extent of the training is dictated not only by the number of the personnel involved but also by the complexity of the mission. The training includes joint operations with other launch and flight support organizations. OMV simulations are required to support the training and to support the mission as an engineering analysis tool.

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Design and Performance Requirements

CONTROL STATIONS

Ground Control - Provided by the OMV Program
- Commands, Control, Data via S/C Tracking & Data Network (STDN)

Computer
- Software, Keyboards, CRT's Peripherals
- Interactive Displays - Operators Will Build
- Man-Interactive Control of OMV
- Mission Planning

Consoles/Conference Areas for Mission Operations
- Operations Direction
- Command Uplink
- Subsystem Engineering
- Mission Planning

Training
- Joint Operations
- Simulations for Training and Engineering Analysis

Space Station Control - Provided by the Station Program
- Requirements Provided by the OMV Program

DESIGN AND PERFORMANCE REQUIREMENTS

Six distinct operational modes are required for the OMV, as shown on the opposing chart.

In the programmed mode the OMV must be capable of automatic operations under control of an on-board computer except for terminal rendezvous and docking operations. The OMV is required to have the on-board computation capability for determining propulsive maneuvers for spacecraft deployment and/or retrieval and return to the proximity of the STS.

In the primary hold mode, the OMV is required to have an inertial hold and local vertical local horizontal hold mode utilizing an inertial reference and a reaction control system for operation, after release by the STS RMS or Station Mobile Remote Manipulator System, and prior to commencement of retrieval operations.

For the automatic hold mode, the OMV is required to place itself into a minimum-power utilization condition as a result of on-board detection of critical failures which result in a mission loss. This mode is interruptable by the GCS but if no GCS command is received within a mission-dependent programmed time, the OMV places itself in the Contingency Hold Mode.

In the contingency hold mode, which could last for at least 9 months, the OMV is passivated into a safe condition for later retrieval by the STS or another OMV. In this mode, the OMV, without a payload, is placed in a stable attitude and all subsystems are powered down to minimum power levels.

In the pilot mode, the OMV is remotely controlled by a ground or Space Station-based pilot during final rendezvous, viewing, circumnavigating, docking, and undocking/separation maneuvers. This mode is applicable with or without a payload.

For the Space Station mode, the OMV is required to incorporate, or be configured to incorporate, provisions for (a) long-term quiescent storage and servicing while attached to the Station, (b) control of the standard operational modes from the control console on the Station with direct line-of-sight communication; and (c) capability to permit its automatic checkout from the Station prior to deployment.

The future capability mode differs from the contingency hold mode in that the OMV is operational for long duration missions, can be powered up by ground command, and can then acquire an inertial reference and transition to the Primary Hold Mode and subsequently to the programmed mode.

Design and Performance Requirements

OPERATIONAL MODES

- Initial
  - Programmed
    - Automatic Operation Except Rendezvous/Docking
    - On-Board Determination of Propulsive Maneuvers
  - Primary Hold
    - Local Vertical - Local Horizontal with Reaction Control System
  - Automatic Hold
    - Minimum Power After On-Board Detection of Failures
    - Interruptable Through GCS Within Programmed Time
  - Contingency Hold
    - Entered From Automatic or By GCS Command
    - Stable Attitude with Minimum Power (No Payload)
    - Passivates OMV for Safe Retrieval Up to 9 Months Later
  - Pilot
    - Control from Ground or Station
    - Collision Avoidance Required if Communications Lost
  - Space Station
    - Long Term Quiescent Storage and Servicing
    - Control of Standard Modes by Line-of-Sight
    - Automatic Checkout Prior to Deployment

- Future Capability
  - Scar for Long Duration Operational Missions

DESIGN AND PERFORMANCE REQUIREMENTS - SIC DESIGN REFERENCE MISSIONS (DRMs)

The OMV is required to satisfy 12 DRMs for the basic OMV and must accommodate upgrading of its capability for 5 future capability missions by the addition of appropriate kits or elements to the system.

The Large Observatory mission requires retrieval of a 25,000 pound observatory from 130 NM above the Orbiter or Station for service at the Orbiter or Station and returning it to the same altitude. The OMV must maneuver the observatory so that the maximum acceleration is less than .002 G if the observatory requires this.

The Payload Placement mission requires the OMV to deliver a 3,500 pound payload to 340 miles above the Orbiter or Station. A 1° plane change is required for each leg of an OMV round trip and the OMV must be capable of returning the payload to the Orbiter or Station if the payload fails to activate properly.

The Payload Retrieval mission requires the OMV to rendezvous, dock and retrieve a payload weighing 11,000 pounds at an altitude of 220 NM above the Orbiter or Station. A 1° plane change is required for each of leg of an OMV round trip.

The Payload Reboost mission requires the OMV to rendezvous and dock with a 25,000 pound payload 100 NM above the Orbiter or Station and reboost it to 220 NM above the Station or Orbiter at the same inclination.

The Payload Deboost to Re-entry mission requires the OMV to rendezvous and dock with a 75,000 pound payload at 160 NM and deboost it to an atmospheric re-entry trajectory after which the OMV returns to the Orbiter or Station.

The Payload Viewing Mission requires the OMV to depart from the Orbiter or Station, rendezvous with and circumnavigate a payload 840 NM above the Orbiter or Station for 4 hours of viewing time. A 1° plane change is required for each leg of the OMV round trip.

The Subsatellite mission requires the OMV to transport a 5,000 pound experiment package to a new orbit location with an in-plane displacement of up to 180° but at the same altitude as the Orbiter or Station. The OMV must provide experiment package orientation and attitude control, and return the experiment package to the Orbiter or Station after termination of the experiment.

The Multipayload missions require deployment of a 5,000 pound payload to an altitude of 85 NM above the Orbiter or Station with no plane change, followed by retrieval of a 10,000 pound payload from 110 NM above the Orbiter or Station.

The Upper Stage mission requires a derivative of the OMV as an upper stage of the TOS to provide the plane change and circularization maneuvers required to inject a payload into geostationary, equatorial orbit.

The early Limited Servicing mission requires the OMV to transport an unprocessed payload module from the Orbiter or Station to a free-flying processing facility, exchange the module for a processed payload module & transfer the module back to the base. The modules/kits to support this mission are provided by the user.

The Space Station Logistics Support mission requires the OMV to provide logistics support between the Station, Space Platforms, Orbital Transfer Vehicles and the Orbiter.

The Space Station Reboost mission requires the OMV to mate with the Station and reboost it.

Design and Performance Requirements

DESIGN REFERENCE MISSIONS

1 - Large Observatory Servicing
2 - Payload Placement
3 - Payload Retrieval
4 - Payload Reboost
5 - Payload Deboost to Re-Entry
6 - Payload Viewing
7 - Subsatellite
8 - Multiple Payloads
9 - Upper Stage
10 - Early Limited Servicing
11 - Space Station Logistics Support
12 - Space Station Reboost

DESIGN AND PERFORMANCE REQUIREMENTS

FUTURE CAPABILITY MISSIONS

The Debris Collection missions require the OMV to rendezvous and attach to space debris, spacecraft in trouble, or obsolete spacecraft and either return them to the Orbiter, boost them to a storage orbit or deboost them to atmospheric entry with the OMV returning to the Orbiter or Station after completion of its mission objective.

The Extended On-Orbit Operation mission requires the OMV to be capable of extended operation at low earth orbit or geostationary orbit.

The Satellite Buildup mission requires the OMV to provide incremental delivery of payload sections on-orbit, providing attitude control, drag makeup and support services in a "holding" orbit. With delivery of the remaining payload section, the OMV must be capable of space operations in support of the maneuvering, alignment, docking and assembly of the total payload, and, subsequently, boosting the completed payload into its operational orbit.

The Satellite Refueling mission requires the OMV to provide in-situ refueling of LEO and GEO satellites with an attached remote fueling tanker kit.

The Servicing mission requires the OMV to support a spacecraft servicing kit for accomplishing remote servicing on a satellite or space platform. For low earth orbit, the OMV must return with the servicing kits to either the Orbiter or Station. For geosynchronous orbits, the OMV must accomplish the required servicing and enter an on-orbit storage mode.

Design and Performance Requirements

FUTURE CAPABILITY MISSIONS

1 - Debris Collection
2 - Extended On-Orbit Operation
3 - Satellite Buildup
4 - Satellite Refueling
5 - Servicing

DESIGN AND PERFORMANCE REQUIREMENTS

LAUNCH OPERATIONS

The OMV is required to be capable of launch from either the KSC Eastern Test Rage (ETR) or the Vandenberg Air Force Base Western Test Range (WTR). The OMV and support equipment, and procedures must allow rapid turn-around and minimum on-line operations at the launch site, and be compatible with either vertical or horizontal cargo bay installation options. Capability for battery and other selected items changeout in the cargo bay is required.

MISSION OPERATIONS

Mission Operations are the efforts involved in operating the OMV as a free-flying satellite. Mission Operations are conducted from the Control Station(s) located on the ground and/or Station.

The OMV deployment and retrieval functions performed by the STS crew are limited to standard crew-provided services as required by Orbiter Safety criteria such as monitor, enable and inhibit. The OMV is controlled through the Ground Control Station subsequent to deployment and prior to the Orbiter RMS grappling.

The mission planning in the Ground Control Station includes support for ephemerides updating, TDRSS scheduling through the STDN schedule system, real-time control operations, OMV simulations and data management.

Design and Performance Requirements

LAUNCH OPERATIONS

KSC Eastern Test Range
Vandenberg Air Force Base Western Test Range
Rapid Turn-Around with Minimum On-Line Operations
Compatible with Vertical or Horizontal Orbiter Installation
Battery/Selected Item Changeout in Cargo Bay

MISSION OPERATIONS

Orbiter Crew Functions Limited to Standard Crew Procedure Services
Mission Planning Activity is in the GCS
TDRS Scheduled thru the STDN System
Engineering Data Analyses
Support Operations/Data Management

DESIGN AND PERFORMANCE REQUIREMENTS

The opposing page summarizes the interfaces between the OMV and the Space Shuttle Orbiter. On an as required basis the OMV must provide a telemetry interface to and a command interface from the Orbiter via hardwire and via the Payload Interrogator, or via a future operations technique which totally bypasses the payload interrogator or General Purpose Computer systems.

Structural, electrical, and command/data interfaces to the payloads have been previously discussed.

The OMV must be capable of berthing with the Station. The capture and deployment of the OMV by the Station shall be compatible with Orbital docking provisions and the OMV must be capable of on-orbit storage at, and support by, the Station.

Design and Performance Requirements

SUBSYSTEMS

STRUCTURES & MECHANISMS
- Ten Year Life and 100 Launch and Landings
- Provide for Future Capability Add-on Kits
- Dock with RMS Grapple Fixture, Space Telescope type, and others
- Accommodate Cantilevered Payloads with Mass/C.G. Offset of 10,000 Ft/Lbs

THERMAL CONTROL
- Use STS Payload Bay Purge Gas During Ground Operations as Required
- Provide Conditioning While OMV is in STS Payload Bay
- OMV Orientation Restrictions Permitted Only During Passive Phases
- Minimize Heat Transfer Between OMV/Payload and OMV/Station

PROPULSION
- Three-Axis Attitude Control
- Three-Axis Maneuverability
- Accommodate On-Orbit Fluid Resupply/Servicing
- Include Cold Gas Nitrogen RCS for use Near Contamination Sensitive P/L's

GUIDANCE, NAVIGATION AND CONTROL
- Six Degree-of-Freedom Control During
  - Target Operations and Docking
  - Maneuvering of OMV/Spacecraft Combination
- Automatic Rendezvous to a Preprogrammed Distance From Target S/C
- Attitude Hold and Attitude Rate Hold
- Running Lights for Visibility and Orientation
- Inertial Reference System Update for Extended Capability Modes

DESIGN AND PERFORMANCE REQUIREMENTS

SUBSYSTEMS

ELECTRICAL

The Electrical Power Subsystem must satisfy the key requirements shown on the opposing page, provide a minimum of 5 kWh of electrical energy to the payload user, and must have the capability to deliver the electrical energy at a peak 1 kW rate for 5 continuous hours or at a lower power level over an extended period as the user demands.

COMMUNICATION AND DATA MANAGEMENT (C&DM)

The C&DM subsystem must provide all equipment required for receiving/decoding commands, transmitting telemetry and transmitting TV. It includes all the hardware required for the processing and distribution of commands, and for the acquisition, processing and distribution of telemetry data. TV cameras and lighting to accomplish docking and payload viewing missions under full daylight or dark side conditions, are also included. The key requirements are shown on the opposing page.

SOFTWARE

The software for OMV includes all the necessary computer instructions to accomplish the mission, provide support computations and to checkout, verify and validate hardware and software. The categories of software for which NASA MSFC has generated specific requirements are shown on the opposing page.

Design and Performance Requirements

INTERFACES

Installation in Multiple Cargo Bay Active Positions
RMS Grapple Fixture is EVA Removable
Optical/Radar Targets, Docking Aids as Required by STS
Interface with STS T-O Umbilical as Required
Mate/Demate Devices in Cargo Bay to Accommodate EVA Backup
Propellant Servicing Devices Require Unique Couplings
TM/Command Interface to STS as Required
Proximity Operations Compatible with STS Rendezvous/Retrieval Profiles
Enable, Inhibit, Safety Operations by GCS during Deployment/Retrieval

Payload Interfaces Specified for Structural, Electrical, Commands and Data

TDRSS in Accordance with User's Guide

Upper Stages Include TOS, Centaur, and OTV

STATION

On-Orbit Storage and Support by Station
S-Band RF Interface Compatible with OMV to STDN Link

DESIGN AND PERFORMANCE REQUIREMENTS

SUBSYSTEMS

STRUCTURES AND MECHANISMS

The OMV structure design must accommodate a full or partial propellant load and a design fatigue life factor of four. This subsystem must provide the structural capability and attachment interfaces required to install add-on kits required for future capability missions.

THERMAL CONTROL

The key requirements are summarized on the opposing page.

PROPULSION

The Propulsion subsystem must provide the impulse necessary to perform the velocity change maneuvers required by the basic design reference missions. It must be designed for multiple reuse with maintenance and refurbishment. Other key requirements are summarized on the opposing chart.

GUIDANCE, NAVIGATION AND CONTROL (GN&C)

The GN&C in conjunction with the Propulsion Subsystem and the Communications and Data Management (C&DM) subsystem must satisfy the key requirements shown on the opposing chart.

DESIGN AND PERFORMANCE REQUIREMENTS

SUBSYSTEMS (Continued)

ELECTRICAL

- Power Distribution via Redundant Power Buses
- Peak-Power-Tracking for Solar Array Battery Charging as Required
- Provide Minimum of 5 kWh to payload user
  - 1 kW rate for 5 Continuous Hours or Lower Power Over Longer Period
- Provide Cantilevered Payload Ground Circuit Routing Through OMV to STS T-O Umbilical

COMMUNICATIONS AND DATA MANAGEMENT

- Compatibility with TDRSS, GSTDN, DSN, Ground Networks and Station
- Minimum of 2 TV Cameras, One With Pan/Tilt/Zoom Capability
- Illumination of Target During Docking Operations
- Throughput Serial Digital Data at Video Rate When OMV TV Not Used
- Provide Payload with Serial Digital Command Data
- Provide Computational Capabilities (memory at PDR will be twice Estimated Requirement)
- Minimize Deployed Appendages Consistent with Required Antenna Coverage

SOFTWARE

- Flight
- Ground Control Station
- Space Station Control Station Requirements
- GSE
- Mission Operations
- Mission Planning

RELIABILITY REQUIREMENTS

The overall NASA reliability requirements have been tailored for the OMV by NASA-MSFC. The key requirements are summarized on the opposing chart. OMV redundancy must be capable of checkout during flight through the OMV ground control station.

The OMV environmental, maintainability, safety, design and construction standards, system verification, logistics and quality assurance requirements are not discussed in this paper in the interest of brevity.

RELIABILITY REQUIREMENTS

No two credible failures shall result in loss of life, STS or the Station.

No single failure shall produce loss of the STS mission, loss of the OMV or OMV payload, or OMV mission.

Provide on-board failure detection, isolation, and automatic redundancy switching where necessary to avoid failure effects.

587–85

ORBITAL TRANSFER VEHICLE (OTV)

by

R.E. AUSTIN
D.R. SAXTON

ADVANCED SPACE TRANSPORTATION GROUP

GEORGE C. MARSHALL SPACE FLIGHT CENTER

paper presented at

RENDEZVOUS AND PROXIMITY OPERATIONS WORKSHOP
PLANNED CAPABILITIES PLENARY SESSION
LYNDON B. JOHNSON SPACE CENTER
FEBRUARY 20, 1985

588-85

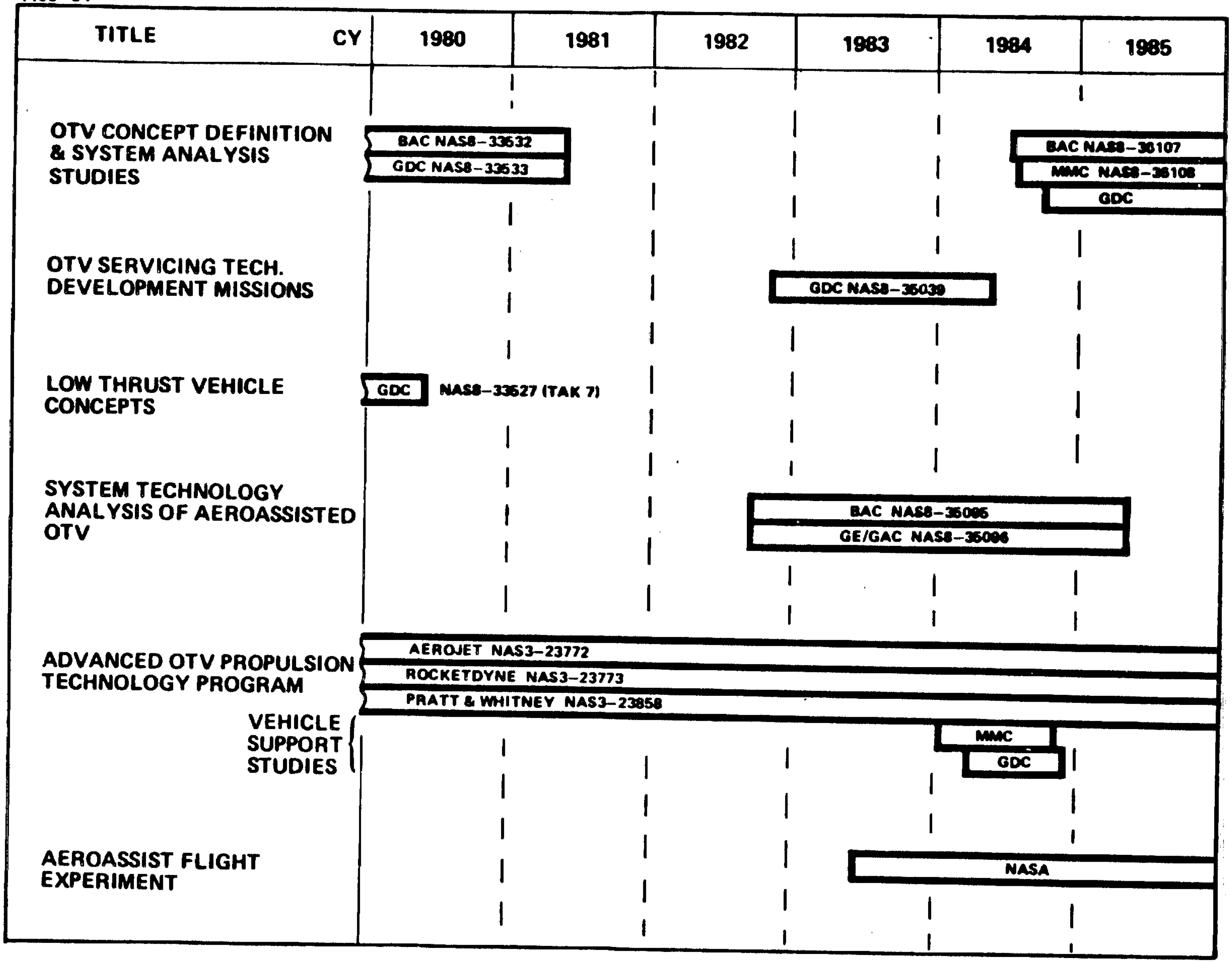
ORBITAL TRANSFER VEHICLE (OTV)

- OTV IS AN UPPER STAGE FOR THE STS WHICH WILL BE USED TO TRANSFER PAYLOADS FROM LEO TO HIGH ENERGY ORBITS
- CURRENT PHASE A STUDIES ARE INVESTIGATING THE FOLLOWING OTV ATTRIBUTES:
  - OTV EXTENDS REUSABILITY IN SPACE TRANSPORTATION TO HIGH ENERGY ORBITS
  - AEROASSIST TECHNOLOGY ENABLES COST EFFICIENT OTV REUSABILITY
  - SPACE BASED OPERATION PROVIDES ADDITIONAL COST BENEFITS
    - PROPELLANT DELIVERY
    - PAYLOAD MANIFESTING
    - OTV SERVICING
  - EVOLUTION TO MANNED OTV MISSION CAPABILITY
    - MODULAR SPACE BASED CONCEPT
    - USE OF ADVANCED OTV PROPULSION TECHNOLOGY
- COST EFFECTIVE ACCOMMODATIONS FOR OTV AT SPACE STATION ARE ALSO BEING INVESTIGATED IN THE PHASE A STUDIES
  - PROPELLANT STORAGE
  - OTV SERVICING
  - SPACE STATION AS A TRANSPORTATION NODE

NEAR TERM OTV ACTIVITIES

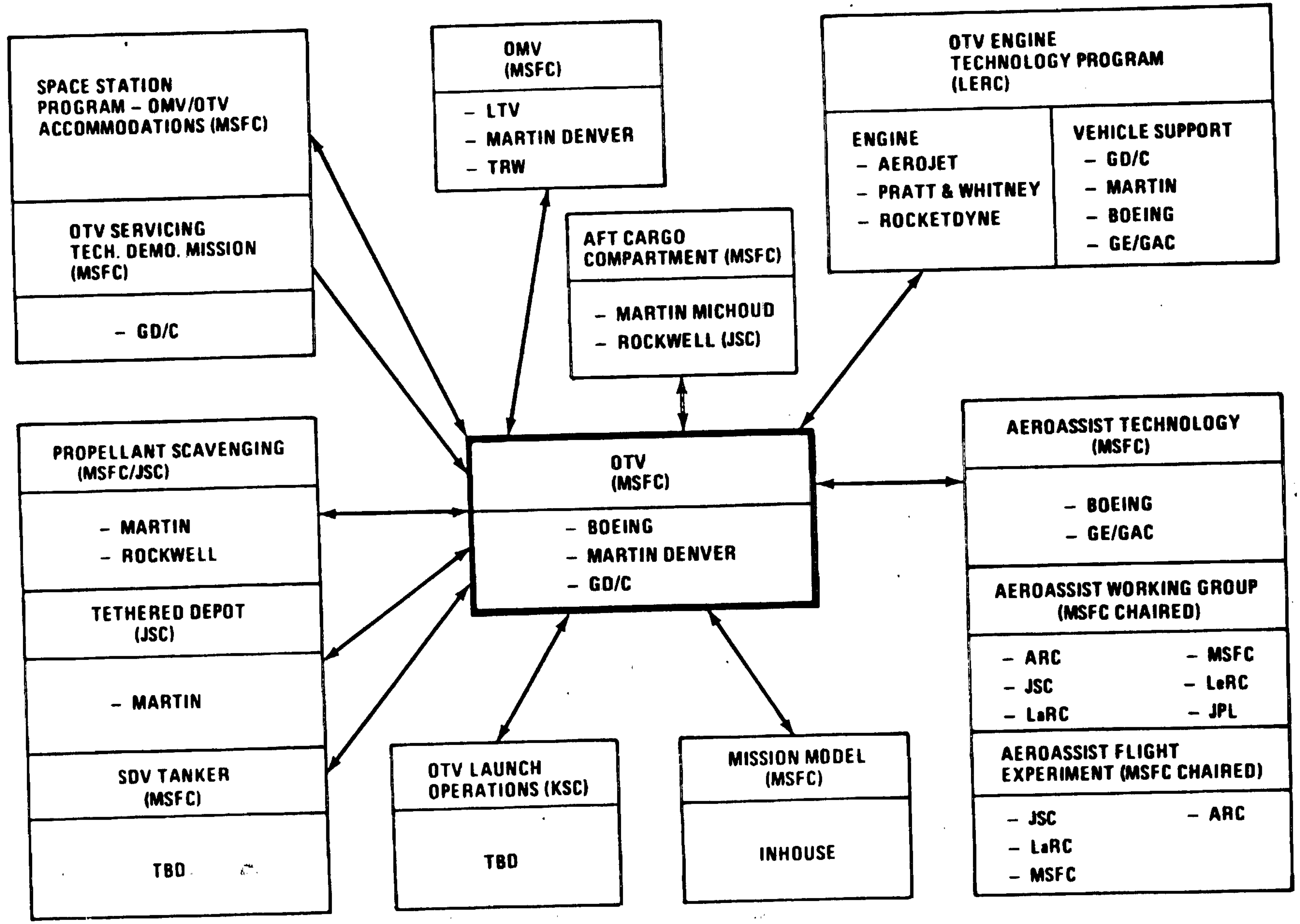
SAXTON 10-12-84

4400-84



599–85

ORBITAL TRANSFER VEHICLE INTERFACES



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ORBITAL TRANSFER VEHICLE CONCEPT DEFINITION AND SYSTEM ANALYSIS STUDIES

OBJECTIVES:

- INVESTIGATE ALTERNATIVE OTV CONCEPTS AND CONDUCT PROGRAM LEVEL STUDIES AND ASSESSMENTS WHICH WILL ALLOW FOCUSING THE OTV PROGRAM TOWARD FUTURE DEVELOPMENT.
- DEFINE POTENTIAL SPACE STATION ACCOMMODATIONS HARDWARE ELEMENTS, RESOURCES, AND INTERFACES NECESSARY TO SUPPORT A SPACE BASED OTV FLEET.

CONTRACTOR DATA:

- TWO PARALLEL STUDIES UNDER COMPETITIVELY AWARDED CONTRACTS
  - BOEING AEROSPACE COMPANY (SEATTLE, WA)
  - MARTIN MARIETTA AEROSPACE (DENVER, CO)
- ONE PARALLEL STUDY CONDUCTED UNDER COMPANY FUNDS
  - GENERAL DYNAMICS/CONVAIR (SAN DIEGO, CA)
- $1M EACH STUDY (OR EQUIVALENT)

DURATION: 15 MONTHS, INITIATED JULY 1984 (CONTRACTS)

MSFC TECHNICAL MANAGER: DONALD R. SAXTON, PS03

HQ MANAGERS: JAMES P. NOLAN, MTS
REMER C. PRINCE, S

OTV STUDY OBJECTIVES

- DEFINE BEST REUSABLE OTV SYSTEM CONCEPT TO MEET EVOLVING MISSION REQUIREMENTS
  - 20K PAYLOAD DELIVERY TO GEO
  - 14K MANNED ROUND TRIP TO GEO
  - 5K PAYLOAD TO MOON
  - 80K UP/15K RETURN MANNED LUNAR SORTIE
- DEFINE SPACE STATION ACCOMMODATION REQUIREMENTS
  - HANGAR AND BERTHING
  - MAINTENANCE
  - REFUELING
- RESOLVE BEST PROGRAM AND DESIGN APPROACH
  - START GROUND–BASED OR SPACE–BASED
    - AFT CARGO CARRIER OR SHUTTLE BAY LAUNCH
  - CRYOGENIC OR STORABLE PROPELLANTS

PROGRAM CHALLENGES

- OTV MUST COMBINE MANY NEW CAPABILITIES
  - REUSE
  - ATMOSPHERIC BRAKING AND TRAJECTORY CONTROL
  - SPACE—BASED OPERATIONS
  - MANNED MISSIONS
- WIDE SPECTRUM OF PROGRAM LEVEL TRADES/CONSIDERATIONS
  - ACC OR SHUTTLE BAY LAUNCH
  - GROUND—BASED OR INITIALLY SPACE—BASED
  - CRYOGENIC OR STORABLE PROPELLANTS
  - SPACE MAINTAINED AND LAUNCHED
  - PLANNED EVOLUTIONARY GROWTH
  - PHASED TECHNOLOGY INCORPORATION

KEY DESIGN ISSUES

GROUND–BASED

- PROPELLANT SELECTION
- ACC CONFIGURATION
- RETRIEVAL CONCEPT
- GROUND–BASED AEROASSIST CONCEPT
- REDUNDANCY FOR STS SAFETY
- 1–LAUNCH DELIVERY CAP.
- EVOLUTION TO SPACE–BASING
- IOC DATE
- DEVELOPMENT COST

SPACE–BASED

- PROPELLANT SELECTION
- STORABLE STAGING CONCEPTS
- SB AEROASSIST CONCEPT
- DESIGN FOR SPACE MAINTENANCE
- EVOLUTION TO MAN–RATING
- TOTAL PROPELLANT REQUIRED
- LIFE CYCLE COST
- TECHNOLOGY LEVEL
- SPACE STATION ACCOMMODATIONS

TECHNICAL ISSUES

AREA	KEY ISSUES	ASSESSMENT APPROACH
AEROASSIST	AEROSPIKE L/D SURFACE TEMPERATURE STOWAGE MECHANISMS REUSABILITY/MAINTAINABILITY	WIND TUNNEL EVALUATION WEIGHT VS DELTA V TRADE ALLOWABLE TEMPERATURE VS SIZE/WEIGHT TRADE WEIGHT FOR MECHANISMS VS EXPENDABLE TRADE EVALUATE TILE/FABRIC TECHNOLOGY
STRUCTURE	SPACE–BASED MIN GAGE TANK REFLIGHT TESTING LIGHTWEIGHT MATERIALS SP BASE/ACC ARRANGEMENT	EVALUATE MANUFACTURING TECHNOLOGY TEST TECHNOLOGY EVAL. REPAIR/REPLACE TRADE COMPOSITES/MATERIALS TECH EVAL TRADE CONFIGURATION CONCEPTS
AVIONICS	AEROASSIST NAV ACCURACY CONTROL ALGORITHMS REUSABILITY/MAINTENANCE	SENSOR/TRACKING TECHNOLOGY EVALUATION CLOSED LOOP SIMULATIONS MTBF/PACKAGING TRADES
PROPULSION	PROPELLANT SELECTION LIFE AND REUSE PROPELLANT MANAGEMENT ACS TECHNOLOGY	TRADE ISP AND THERMAL CONDITIONING LOGISTICS COST AND EVALUATE DDT&E COST SUBSYSTEM (PRES, VENT, ETC) TRADES TRADE CONVENTIONAL WITH CMG'S, ET AL
OPERATIONS	ACC CONFIGURATION RETRIEVAL COMMAND AND CONTROL FOR AEROMANEUVER SPACE BASE PROX OPERATIONS SPACE MAINTENANCE OPERATIONS	FUNCTIONAL REQUIREMENTS OPERATIONS PLANNING PART TASK SIMULATION

594–85

UNIQUE STORABLE ISSUES

- MODULARITY –– A STRONG DRIVER
  - EFFICIENT MISSION TAILORING
- OMV AND RCS COMMONALITY
  - SPACE STATION FACILITIES AND SERVICES
- MULTI–ENGINE DESIGN NECESSITY
  - 3750–LB THRUST IS IN DEVELOPMENT
- SDV TANKER
- DELIVERY AND EVOLUTION
  - PERIGEE KICK STAGE –– STARTING POINT

595-85

UNIQUE CRYO ISSUES

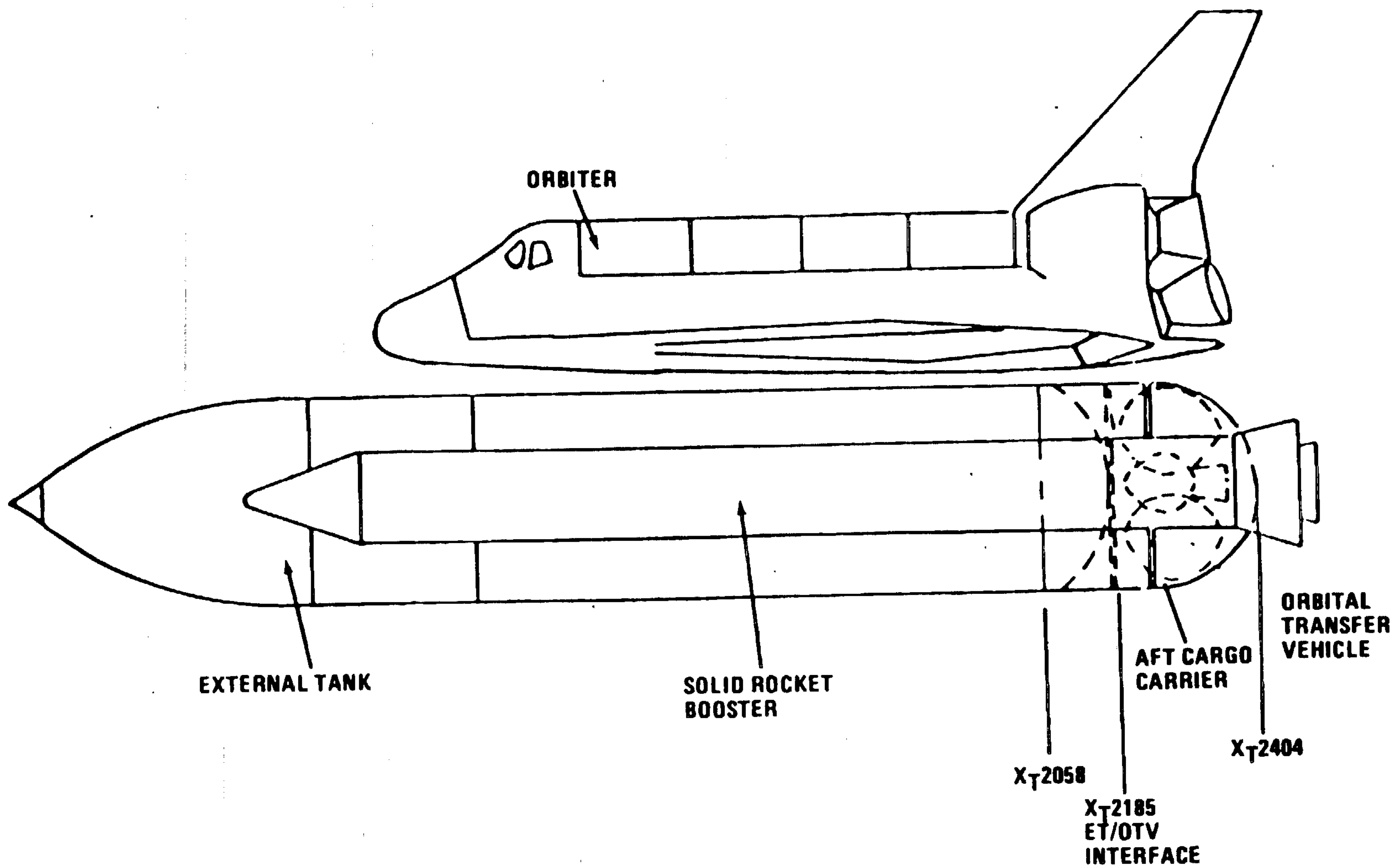
- PROPELLANT SCAVENGING
  - SIGNIFICANT QUANTITIES AVAILABLE
  - LOWER COST MAY BIAS OTV OPTIMIZATION
- ENGINE EVOLUTION
  - RL10 DERIVATIVE OFFERS LOW–COST IOC
  - GROWTH SELECTION REQUIRES SCAVENGING/TRAFFIC EVALUATION
- SPACE–BASE PROPELLANT STORAGE
  - ACTIVE, NO VENT SYSTEM REQUIRED
  - OPERATIONS TIMELINES CAN IMPACT OTV AND BASE DESIGN
- MISSION DURATION CAPABILITY
  - LONG MISSIONS INCREASE LH_2 SYSTEM COMPLEXITY
  - SERVICING MISSION IMPLEMENTATION IMPORTANT TRADE

ORIGINALS FOR

Pages 3-145 and 3-146

ARE NOT AVAILABLE

ACC OTV INSTALLATION



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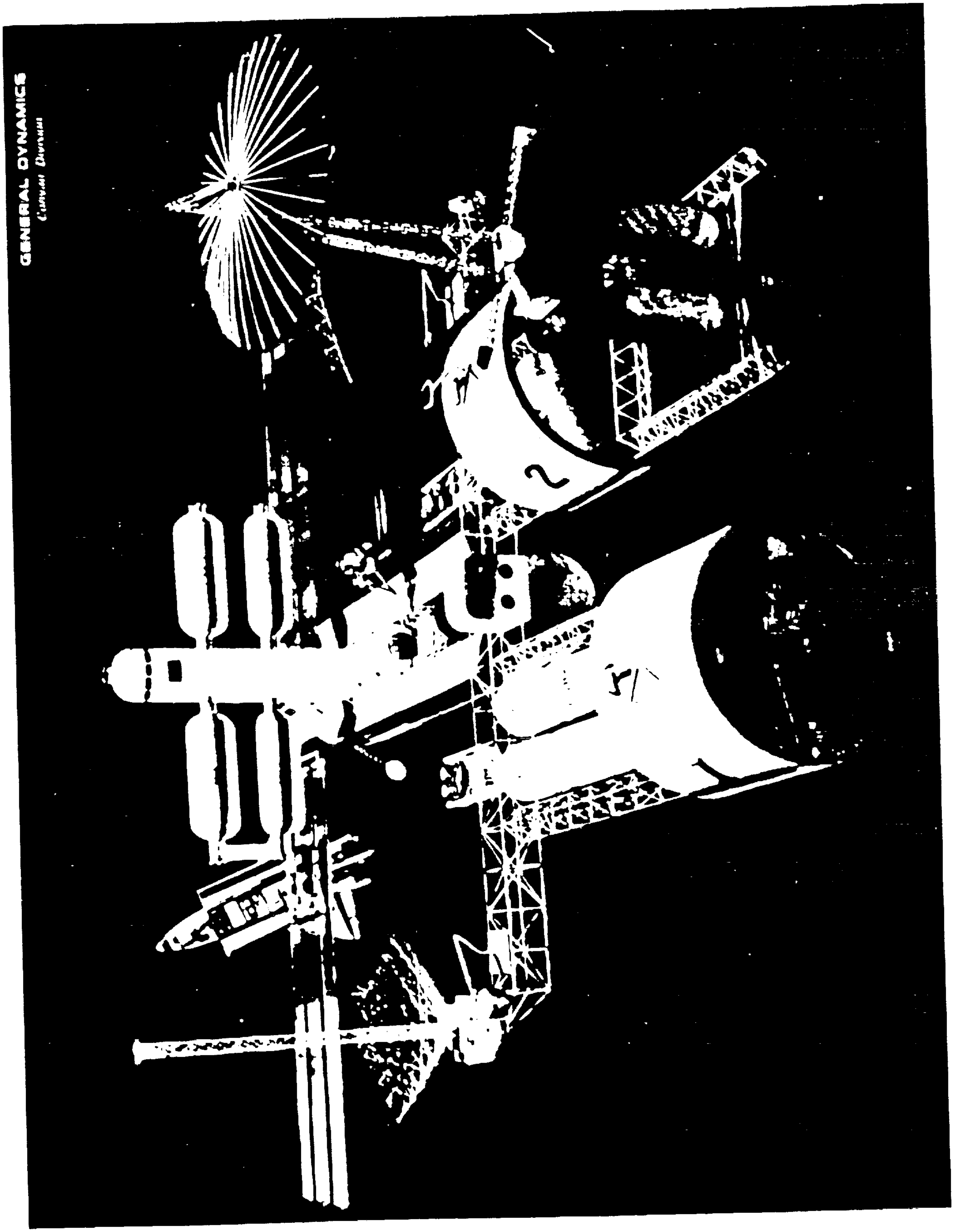
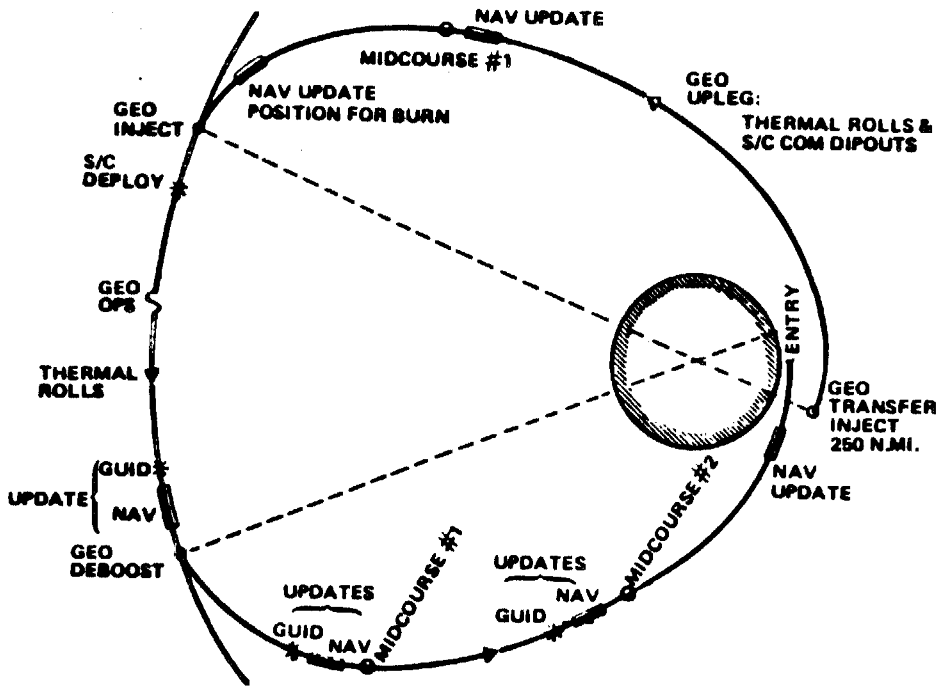
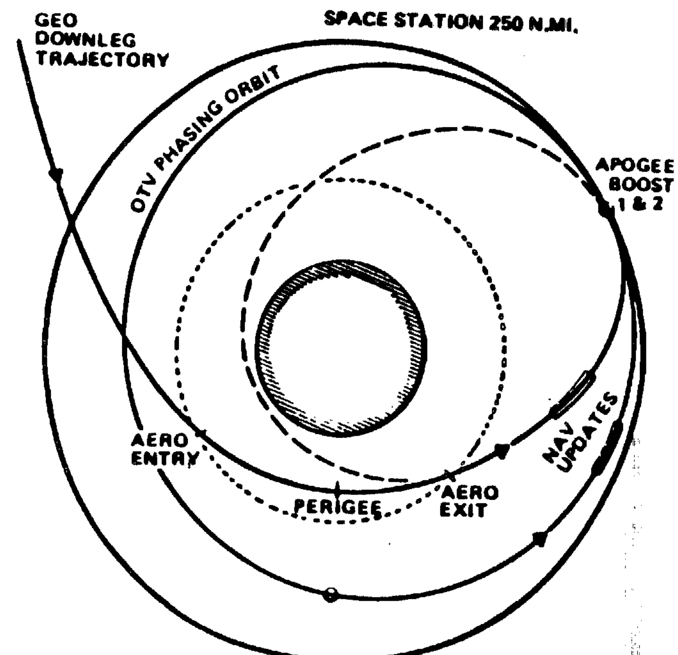

GENERAL DYNAMICS

TYPICAL OTV MISSION PROFILE



TRANSFER PHASE



AERO PHASE

2886-84

OTV PERFORMANCE IMPROVEMENT OPTIONS

VEHICLE	BASING	GEO MISSION MODE		
		EXPENDABLE DELIVERY	REUSABLE DELIVERY	ROUNDTRIP
CENTAUR *	GROUND	13,600	0	0
ALL PROPULSIVE OTV *	GROUND	17,400	5,000	1,500
AEROBRAKING OTV *	GROUND	–	12,000	7,000
AEROBRAKING OTV $W_p = 52,000$	SPACE	32,000	26,000	14,000

* 65K SHUTTLE

ORBITAL TRANSFER VEHICLE KEY TECHNOLOGY AREAS

- AEROBRAKING
  - STRUCTURES/MATERIALS
  - AEROTHERMODYNAMICS
  - AERODYNAMICS
  - ADAPTIVE GUIDANCE AND CONTROL
- PROPELLANT MANAGEMENT
  - THERMAL CONTROL/CONDITIONING
  - TRANSFER
  - ACQUISITION/GAGING
  - SCAVENGING
- STRUCTURES & MATERIALS
  - LIGHTWEIGHT TANKAGE
  - COMPOSITES
  - METEOROID/DEBRIS PROTECTION
  - FABRICATION/ASSEMBLY TECHNIQUES
- PROPULSION
  - ENGINE PERFORMANCE
  - HEALTH MONITORING/FAULT TECHNIQUES
- AVIONICS
  - IMPROVED COMPONENTS (WEIGHT, CAPABILITY, LIFE, RELIABILITY)
  - ADVANCED INFORMATION PROCESSING
  - REDUNDANCY MANAGEMENT
- OPERATIONS
  - EQUIPMENT/FACILITIES
  - SPACE MAINTAINABILITY
  - AUTOMATION DEVELOPMENT

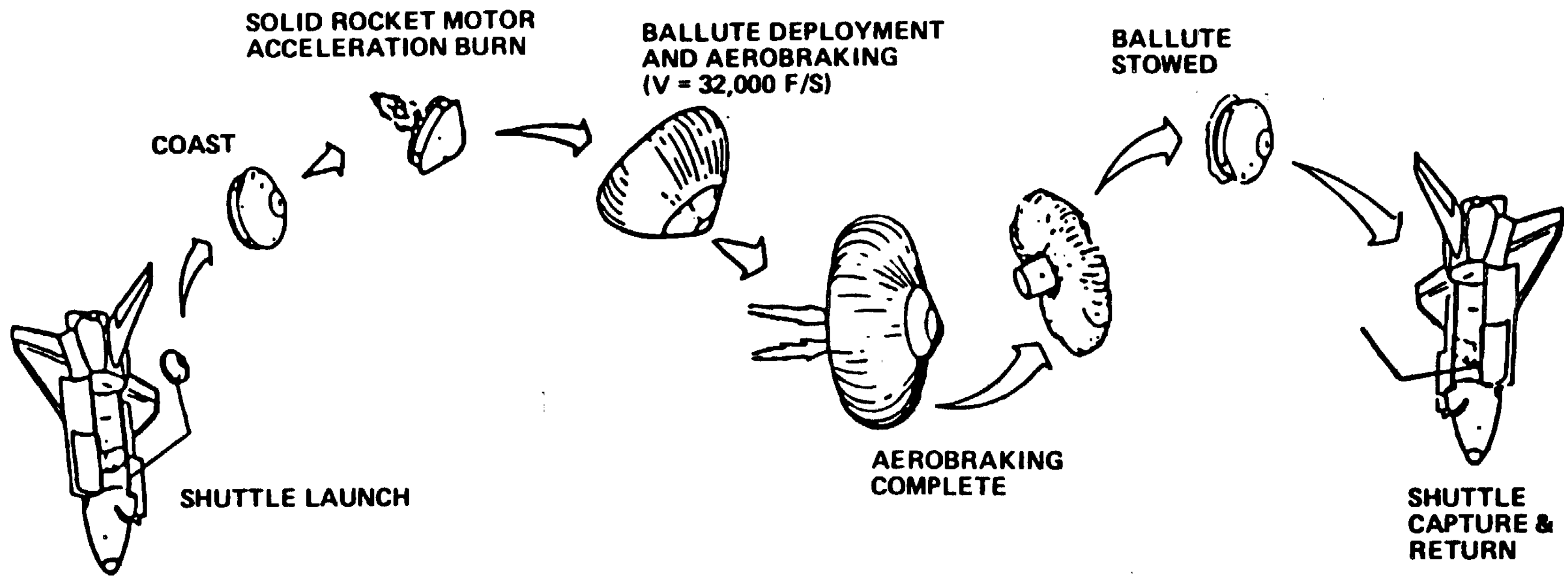
ORIGINALS FOR

Pages 3-153 and 3-154

ARE NOT AVAILABLE

598–85

AEROBRAKING FLIGHT EXPERIMENT



SIMPLE ORBIT TO ORBIT TEST
ALLOWS DEMONSTRATION
OF CRITICAL TECHNOLOGY ITEMS

- FLEXIBLE TPS
- AEROTHERMAL RESPONSE
- GUIDANCE & CONTROL

FUTURE SPACE AND GROUND NETWORK CAPABILITIES

- GSTDN
- TDRSS
- ATDRSS
- TDAS
- NAVSTAR / GPS

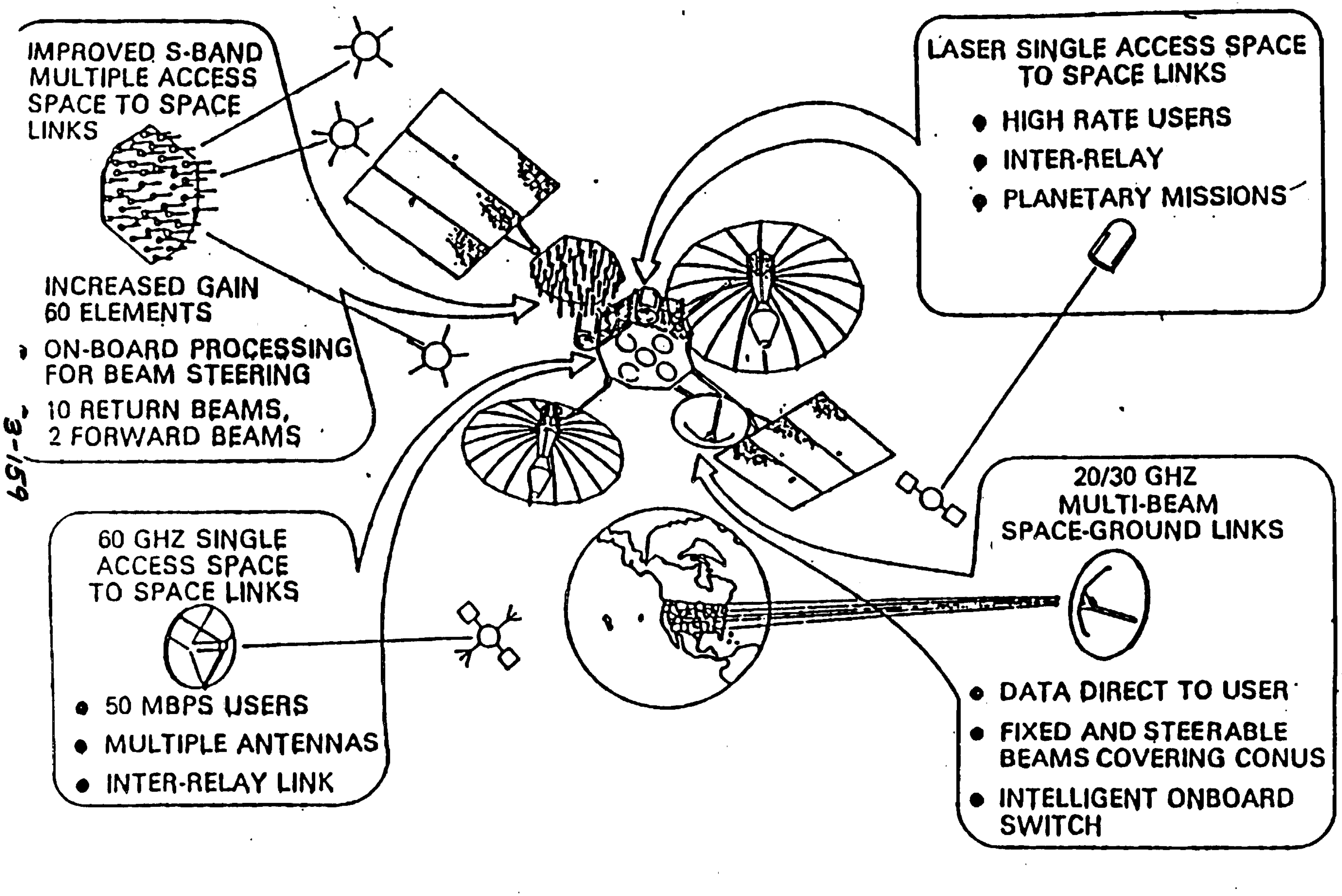
NETWORK AUGMENTATION OPTIONS AND ALTERNATIVES

- TDRSS
  - IMPROVE NETWORK OPERATIONS, INCREASE NETWORK RELIABILITY
  - POSSIBLE SHUTTLE LANDSAT RENDEZVOUS/RETRIEVAL SUPPORT
- AUGMENTED TDRSS (ATDRSS)
  - MEET NASA TRAFFIC REQUIREMENTS FOR 1990'S ERA
  - SUPPORT SPACE STATION AND A MULTITUDE OF PLATFORMS
  - SUPPORT OTV AND RENDEZVOUS/RETRIEVAL ACTIVITIES
- ADVANCED TDRSS (TDAS)
  - ADDITIONAL CAPACITY BEYOND THE YEAR 1998

STUDIES AND OPTIONS FOR RENDEZVOUS AND PROXIMITY OPS

- TDRSS
  - STUDY EARLY ORBIT ALGORITHMS
  - AIAA PAPER BY SMITH AND HUANG JAN 85
- ATDRSS AND TDAS
  - MULTI BEAM SPACE GROUND LINKS (USER/GROUND)
  - POSSIBLE NEW SERVICE - NAVIGATION BEACON
  - FOR USER ON-BOARD ORBIT AND TIME DETERMINATION
  - NEAR CONTINUOUS BEACON SIGNAL LOWERS OD UNCERTAINTY
  - OD UNCERTAINTY DOWN TO 10 METERS?

TDAS TECHNOLOGY



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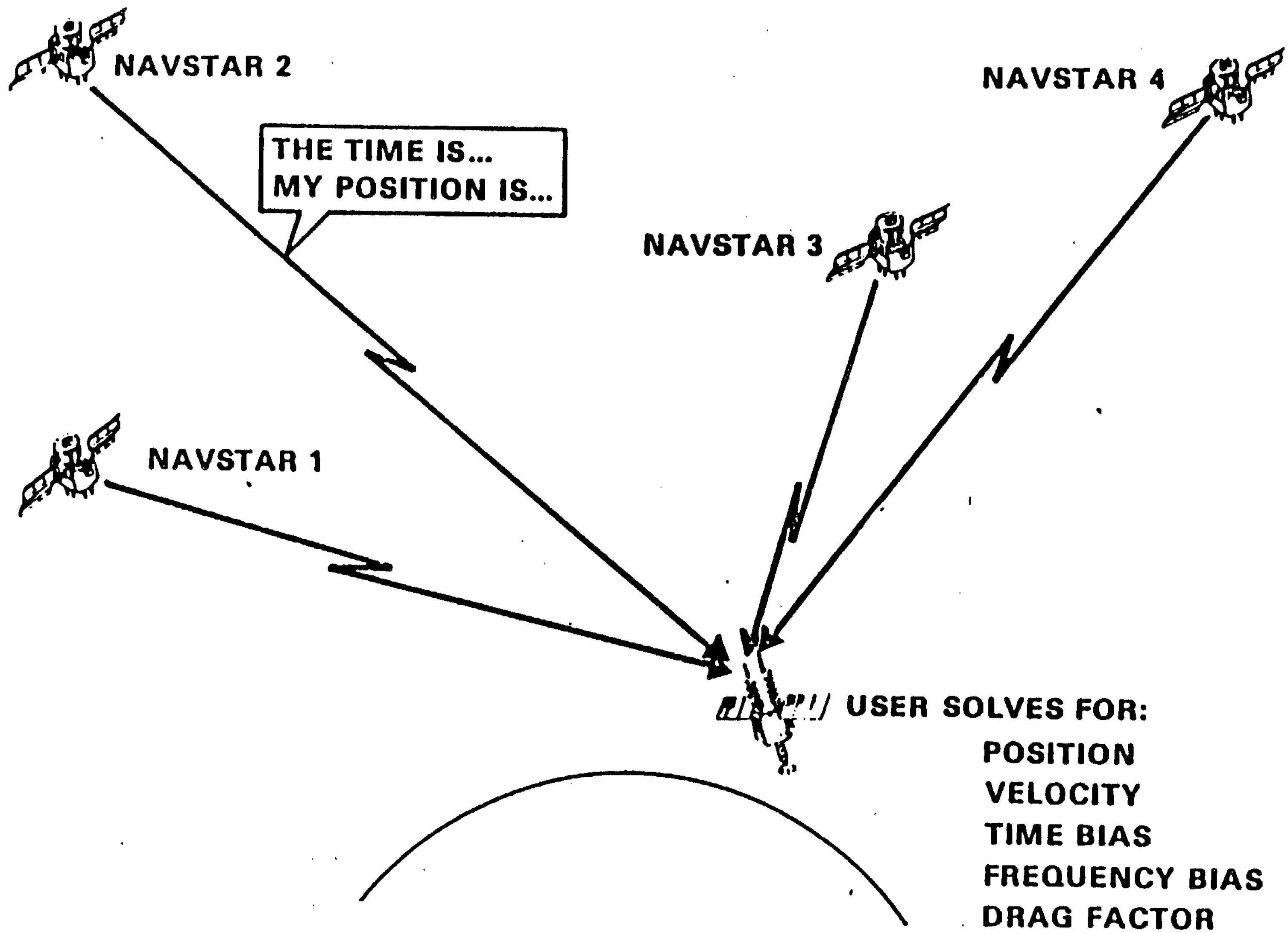
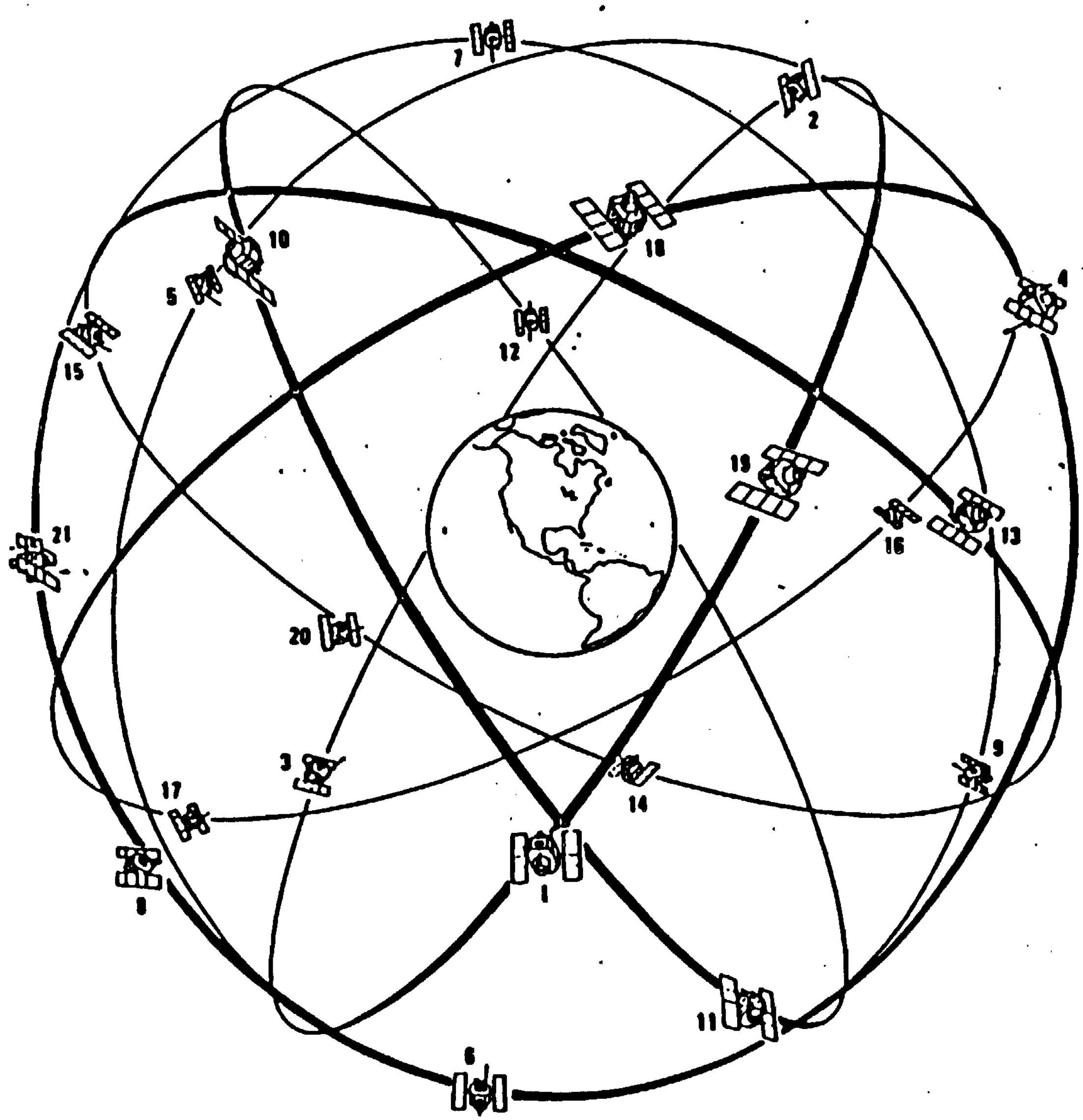
ONBOARD NAVIGATION WITH GPS



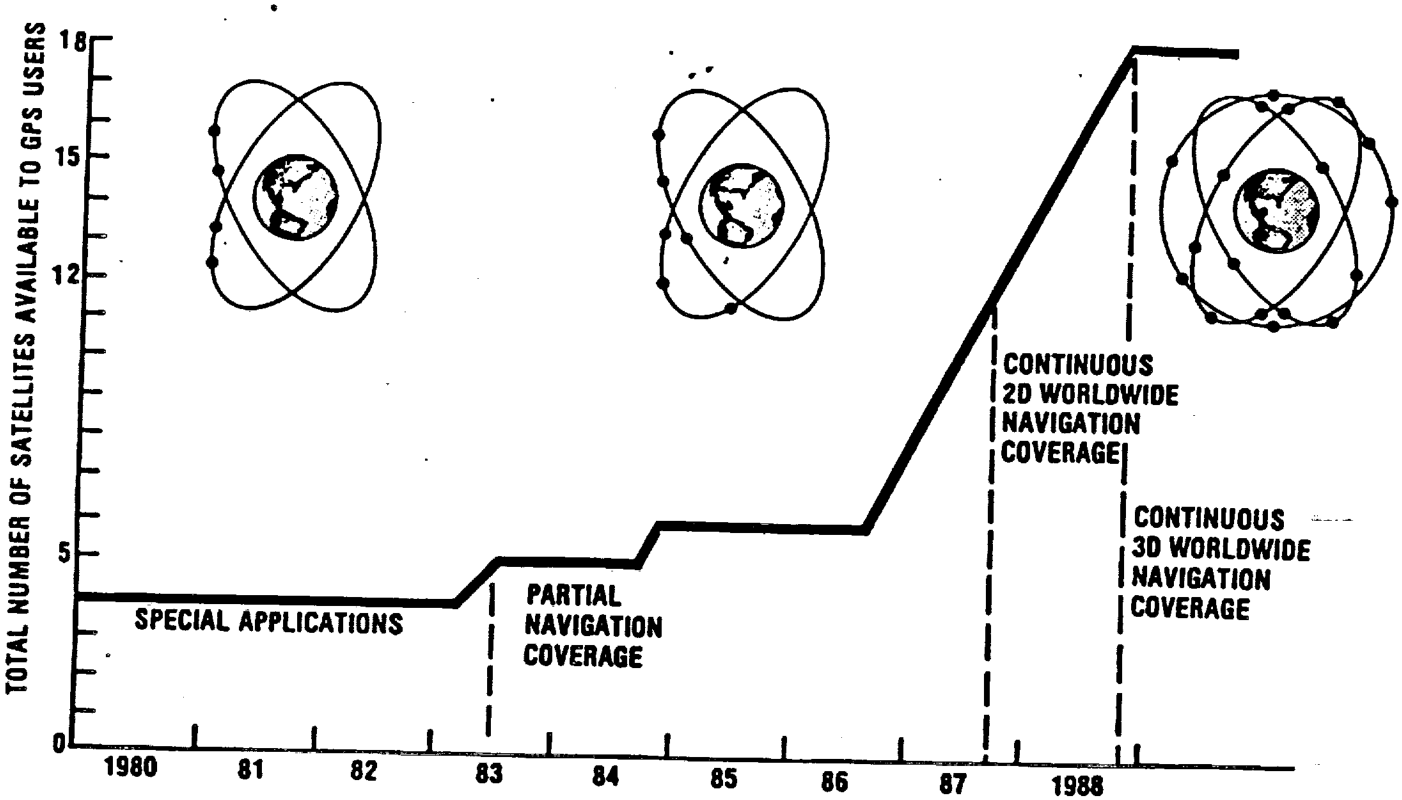
The Navstar Operational Constellation

18 SATELLITES PLUS 3 ACTIVE SPARES



GPS NEWSLINE
THIRD QUARTER 1984

GPS SATELLITE LAUNCH SCHEDULE



TI-4100-08-84

SATELLITE LAUNCHES ARE SUCCESSFUL

The Department of Defense launched its ninth GPS satellite on 13 June 1984 from Vandenberg Air Force Base, California. The launch had been originally scheduled for April but was delayed for further testing and analysis of the Star-48 motors used to achieve orbit after separation of the Atlas-E booster. The Star-48 had failed to insert the Westar and Palapa satellites into orbit from a Space Shuttle Mission earlier this year. The tests have been completed, and the situation has been rectified.

The tenth satellite (PRN #12) is scheduled to be launched in September.

After a period of calibration and testing, this GPS satellite will be made available in the preoperational GPS constellation. These launches will bring the total number of available satellites to six. The satellites fully operational for navigation are: PRN #6, PRN #8, PRN #9, PRN #11, PRN #13, and PRN #12. One additional satellite from the Block I satellites has been left in reserve, but can be launched if needed.

TEXAS INSTRUMENTS

GPS LANDSAT EXPERIMENTS

- EXPERIMENTAL GPSPAC FLOWN ON LANDSAT-4
  - FIRST NASA SPACEBORNE NAVIGATION SYSTEM TO USE THE GPS
  - JULY 82 - JAN 83, ONLY FOUR GPS SPACE VEHICLES AVAILABLE
  - POSITION ERRORS LESS THAN 50 METERS (GOOD VISIBILITY)
- GPSPAC FLOWN ON LANDSAT-5
  - LAUNCH MARCH 84, PERFORMANCE CALIBRATION CONTINUING
- PUBLISHED RESULTS
  - HEUBERGER, PROC. IEEE PLANS '84 (NOV 84)
  - HEUBERGER, CHURCH, AAS/AIAA ASTRODYNAMICS CONF. AUG 83

FUTURE GPS EXPERIMENTS

- ULTRA-PRECISE ORBIT DETERMINATION BY GPS
  - YUNCK AND WU (JPL), AAS PAPER 83-315, AUG 1983
  - LOW EARTH SATELLITE CARRIES GPS RECEIVER
  - DIFFERENCE OBSERVATIONS WITH GROUND RECEIVERS
  - LESS THAN 1 METER ACCURACY (ALTITUDES BELOW 600 KM)
- FLIGHT EXPERIMENTS?
  - JPL, NASA GODDARD, ETC.
  - RENDEZVOUS AND RETRIEVAL?

DEFINITIONS

- GSTDN — GROUND SPACEFLIGHT TRACKING AND DATA NETWORK
- TDRSS — TRACKING AND DATA RELAY SATELLITE SYSTEM
- ATDRSS — AUGMENTED TDRSS
- TDAS — TRACKING & DATA ACQUISITION SYSTEM
- GPS — GLOBAL POSITIONING SYSTEM

27 MARCH 1985

SESSION 4 - SPACE TRAFFIC CONTROL

4-1. "ISSUES AND CONSTRAINTS DRIVING SPACE TRAFFIC CONTROL POLICIES - OVERVIEW" - ROSCOE LEE/TRW

4-2. "IMPACT OF SPACE TRAFFIC LEVEL ON SPACE TRANSPORTATION FLEET SIZE" - DOUGLAS MORRIS, JOHN REHDER, THEODORE TALAY, AND NANCY WHITE/NASA LARC

4-3. "OPERATIONAL CONTROL ZONES" - BLAIR NADER AND A. L. DUPONT/NASA JSC

4-4. "PROXIMITY OPERATIONS ANTENNA PATTERN COVERAGE FOR SPACE STATION TRAFFIC CONTROL" - T. CAMPBELL AND E. BRACALENTE/ NASA LARC AND K. KRISHEN/NASA JSC

4-5. "FORMATION FLYING TECHNIQUES" - DAVID HENDERSON/TRW

4-6. "TRAJECTORY CONTROL RENDEZVOUS" - FRED CLARK/LOCKHEED ENGINEERING AND MANAGEMENT SERVICES COMPANY

4-7. "MARS ORBIT AUTOMATED RENDEZVOUS AND DOCKING SYSTEM" - ROBERT ANDERSON/LINCOM

4-8. "RENDEZVOUS G&N TECHNOLOGY NEEDS" - ALLAN KLUMPP/JPL

ISSUES AND CONSTRAINTS DRIVING SPACE TRAFFIC CONTROL POLICIES - OVERVIEW

DR. ROSCOE LEE
TRW DEFENSE SYSTEMS GROUP
HOUSTON, TEXAS

20 FEBRUARY 1985

TRW DEFENSE SYSTEMS GROUP

CONTENTS

- INTRODUCTION/BACKGROUND
- WHO IS INVOLVED IN ESTABLISHING SPACE TRAFFIC CONTROL DESIGNS AND STRATEGIES?
- WHAT ARE THE CHALLENGES AND DESIGN AND OPERATIONS IMPLICATIONS POSED BY SPACE TRAFFIC CONTROL?

TRW DEFENSE SYSTEMS GROUP

INTRODUCTION/BACKGROUND

- OVERVIEW OF THE PROBLEM OF SPACE TRAFFIC CONTROL
  - WHAT IS SPACE TRAFFIC CONTROL?
  - WHO ESTABLISHES THE REQUIREMENTS?
  - WHAT ARE THE MAJOR DESIGN AND OPERATIONS DRIVERS?
- SOLUTIONS TO THESE CHALLENGES TO BE ADDRESSED BY:
  - OTHER PRESENTATIONS IN THIS SESSION
  - OTHER PRESENTATIONS IN THE WORKSHOP
  - FOLLOW-ON ACTIVITIES TO WORKSHOP
- IT'S NOT TOO EARLY TO ADDRESS THE DESIGN AND OPERATIONS CONSIDERATIONS FOR SPACE TRAFFIC CONTROL.

TRW DEFENSE SYSTEMS GROUP

4-5

INTRODUCTION/BACKGROUND

- This presentation is intended to be an introductory overview, which defines what constitutes space traffic control, identifies the parties who must be involved in the development of space traffic control strategies and design, and highlights the major problems to be addressed.

- Other papers within this Workshop session and other sessions will address candidate solutions to these problems. Follow-on action subsequent to this Workshop is expected to continue the discussions and considerations on space traffic control.

- One school of thought is to wait until there is "sufficient" space traffic to warrant the development of space traffic control strategies. The contention of this author is that, because of the implications of space traffic control across many factions of the technical community and the various elements of the "space fleet", the development of space traffic control strategies must begin early to establish mutually acceptable designs and procedures, with cost-effectivity. Evolution of strategies without a master plan can result in inefficient and expensive operations.

4-6

DEFINITION OF SPACE TRAFFIC CONTROL

- SPACE TRAFFIC CONTROL IS DEFINED TO INCLUDE THE FOLLOWING FUNCTIONS ASSOCIATED WITH THE ON-ORBIT INTERACTIONS OF MULTIPLE SPACE SYSTEMS:

  - RENDEZVOUS, STATIONKEEPING (FORMATION FLYING), FLY AROUND, DOCKING AND UNDOCKING, AND EXTRAVEHICULAR ACTIVITIES (EVAs).

  - FLIGHT PLANNING TO ESTABLISH THE SEQUENCE AND SCHEDULE OF RENDEZVOUS AND PROXIMITY OPERATIONS.

  - TRACKING, MONITORING, AND CONTROLLING THE POSITIONS OF THE MULTIPLE BODIES WITHIN SPECIFIED VOLUMES OF INTEREST/INFLUENCE.

  - TRACKING AND MONITORING OF SPACE DEBRIS AND PREDICTION OF POTENTIAL COLLISIONS.

4-7

DEFINITION OF SPACE TRAFFIC CONTROL

Space Traffic Control is defined to include the following functions:

- Active maneuvers associated with rendezvous, stationkeeping, fly-around, docking and undocking.
- The flight design and planning, which establish the trajectories, maneuver sequences, and schedules for the active maneuvers.
- The tracking, monitoring, and control of the trajectories/positions of the interacting space elements within prescribed volumes of interest/influence.
- The tracking and monitoring of space debris which are included or could pass through the space traffic control region and the prediction of potential collisions of the debris with any of the space systems contained within the traffic control region.

APPLICATION OF SPACE TRAFFIC CONTROL

- SPACE TRAFFIC CONTROL IS REQUIRED WHENEVER TWO OR MORE SPACE SYSTEMS ARE PERFORMING RENDEZVOUS, STATIONKEEPING, PROXIMITY OPERATIONS, OR DOCKING WITH EACH OTHER.

  - THE FUNCTIONAL CONTENT OF SPACE TRAFFIC CONTROL IS INDEPENDENT OF THE NUMBER OF INTERACTING SYSTEMS.

  - THE DEGREE OF COMPLEXITY RISES RAPIDLY WITH THE NUMBER OF BODIES WHICH ARE INTERACTING.

APPLICATION OF SPACE TRAFFIC CONTROL

- Although the debris monitoring and collision prediction aspect of space traffic control is required with only a single space flight system in on-orbit operation, "significant" space traffic control operations commence with the rendezvous, stationkeeping, proximity operations, or docking/undocking of two or more space systems.

- Whenever two space systems perform docking or close-vicinity operations with each other, the full span of space traffic control functions is exercised. This includes the active maneuvers of rendezvous, stationkeeping, and proximity operations; the flight planning and scheduling; and the tracking, monitoring, and control of the systems. Therefore, some form of space traffic control is required even for the two vehicle situation.

- Obviously, the space traffic control activities become increasingly complex as the number of participating bodies grows. Not only are there more entities, which must be controlled, but many additional constraints will result from the interactions among these entities. There will be contention for space traffic control resources (e.g., communications and tracking, transportation and servicing operations).

WHO IS AFFECTED BY SPACE TRAFFIC CONTROL STRATEGIES?

- OPERATORS OF SPACE SYSTEMS INVOLVED IN SPACE TRAFFIC CONTROL
  - FLIGHT CREWS (COMMAND AND CONTROL WITHIN AN ACTIVE VEHICLE; COMMAND AND CONTROL OF A REMOTE VEHICLE; TELEPRESENCE OPERATIONS; EVA)
  - GROUND CREWS (COMMAND AND CONTROL OF A REMOTE VEHICLE - MISSION CONTROL ACTIVITIES)
- USERS (E.G., SCIENCE AND APPLICATIONS, COMMERCIAL, SPACE-BASED WAY STATIONS)
  - ONBOARD MISSION/PAYLOAD SPECIALISTS (OPERATING ATTACHED AND DETACHED PAYLOADS)
  - PAYLOAD OPERATIONS CONTROL CENTER PERSONNEL (OPERATING/MONITORING ORBITING PAYLOADS/EXPERIMENTS AS FREE-FLYERS OR ATTACHED TO SPACE VEHICLES OR PLATFORMS)

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WHO IS AFFECTED BY SPACE TRAFFIC CONTROL STRATEGIES?

- Space traffic control will pose significant challenges to (1) the operator of integrated orbital operations, (2) the users of integrated orbital operations, and (3) the developer of systems performing integrated orbital operations.

- Operators are defined to be the flight or ground crews who are responsible for the active maneuvers, such as rendezvous, stationkeeping, fly-around, docking, and EVA.
  - This includes flight crews who either supervise or actively participate in the command and control of a manned flight system (e.g., STS, Space Station); supervise or remotely pilot remote vehicles (e.g., OMV, OTV); perform telepresence operations (e.g., with remote manipulators); or perform ExtraVehicular Activities.
  - Operators include the ground crews who either supervise or actively participate in the command and control of space flight vehicles (e.g., STS, OMV, OTV).

- Users are defined to be the community associated with the operations of the payloads and experiments, which are providing science and applications, commercial, and space-based services.
  - Users include the onboard mission/payload specialists who are tasked with operating attached and detached payloads/experiments.
  - Users also include the Principal Investigators and Payload Operations Control Center (POCC) personnel, who are responsible for the operations and monitoring of orbiting payloads/experiments, which are operating as free-flyers or are attached to space vehicles or platforms.

WHO IS AFFECTED BY SPACE TRAFFIC CONTROL STRATEGIES? (CON'T.)

- BUILDERS
  - MANUFACTURERS OF THE SPACE VEHICLES SUCH AS STS, OMV, OTV, WHICH WILL PROVIDE THE TRANSPORTATION AND SERVICING CAPABILITIES TO USERS AND OPERATORS OF THESE VEHICLES.
  - MANUFACTURERS OF SPACE SYSTEMS SUCH AS SPACE PLATFORMS, FREE-FLYERS, TETHERED SATELLITES.
  - MANUFACTURERS OF THE SPACE STATION ELEMENTS, WHICH SUPPORT SPACE STATION USER AND OPERATOR FUNCTIONS.
  - MANUFACTURERS OF SYSTEMS SUPPORTING SPACE TRAFFIC CONTROL.

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WHO IS AFFECTED BY SPACE TRAFFIC CONTROL STRATEGIES? (Con't.)

- Builders are defined to be the manufacturers of the systems, which participate in space traffic control or implement the space traffic control functions.
  - Builders of the space vehicles that provide the transportation and servicing capabilities, such as the STS, OMV, OTV).
  - Builders of User systems, such as space platforms, free-flyers, and tethered satellites.
  - Builders of Space Stations systems, which support User and Operator functions in the Station (e.g., remote manipulator systems, docking mechanisms, remote-piloting work stations).
  - Builders of systems supporting the space traffic control functions, such as communications and tracking systems.

- These three groups represent both the source of space traffic control requirements and the agents for implementing space traffic control.
  - Each of these groups will have to address meeting their objectives and goals, cost-effectively.
  - Some of the requirements of each of these groups will overlap and be of mutual benefit.
  - There will also be conflicts in the requirements among these groups, which will require compromises.

MAJOR CONSIDERATIONS IN SPACE TRAFFIC CONTROL

- SAFETY
- ENVIRONMENTAL EFFECTS
- DYNAMIC INTERACTIONS
- SERVICEABILITY
- RESOURCE UTILIZATION

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MAJOR CONSIDERATIONS IN SPACE TRAFFIC CONTROL

- The major design and operations drivers for space traffic control strategies include:

  - The highest priority is given to assuring adequate safety margins to manned space flight systems, which are operating in the space traffic control region.

  - The environmental effects of rendezvous, stationkeeping, proximity operations, and docking maneuvers must be controlled to minimize the contamination and hazards imposed upon the systems in the space traffic control region.

  - Dynamics interactions between space systems, both in attached and detached modes, must be controlled to insure safety, structural integrity, and maintenance of desired operating environments for payloads/experiments.

  - High priority must be given to providing efficient, reliable, and cost-effective transportation and servicing functions to the user community, who are operating either as attached payloads/experiments (manned systems or unmanned platforms) or as free-flying systems. The user community desires the least amount of additional hardware and software for participation in space traffic control.

  - A significant aspect of space traffic control is the demands for resource utilization. Within the bounds of the other constraints such as safety and controlled dynamics and operating environments, the maneuvers associated with space traffic control should attempt to minimize the recurring demands on expendable resources, such as propellants.

SAFETY CONSIDERATIONS

- TOP PRIORITY IS MINIMIZATION OF JEOPARDY TO MANNED FLIGHT SYSTEMS AND CREWMEN ON EVAs

- COLLISIONS
  1. "SAFE" STATIONKEEPING SEPARATION DISTANCES
  2. APPROACH CORRIDORS AND SEQUENCES TO MINIMIZE RISK UPON "ERRONEOUS" RENDEZVOUS OR DOCKING BURNS
  3. DEPARTURE CORRIDORS AND SEQUENCES TO MINIMIZE RISK UPON "ERRONEOUS" DEPARTURE BURNS
  4. PROVISIONS FOR MANUAL INTERVENTION, PARTICULARLY ON INCOMING TRAFFIC
  5. MAINTENANCE OF SEPARATION OF TETHERED PACKAGES
  6. DEBRIS MONITORING AND CONTROL

- PROPULSIVE IMPINGEMENTS
  - ESTABLISH STANDOFF DISTANCE PRIOR TO IGNITION OF PROPULSION SYSTEMS
    A. PLUME OF NOMINAL IGNITION
    B. CATASTROPHIC FAILURE OF UPPER STAGE ENGINE (EXPLOSION)

SAFETY CONSIDERATIONS

- The issue is the need to develop space traffic control designs and procedures, which insure the safety of manned space flight systems and flight crewmen, who are performing EVAs.
- The major threats to safety include collisions, propulsive impingements, and inadvertant activation of propulsion, pyrotechnic, or deployable systems.
- Relative to this issue, there are many analogies to the trades associated with air traffic control. Safety is enhanced by low density in the traffic control region with low traffic rate. However, this scenario tends to compromise the economics, which are derived from higher densities and traffic rates.
- Builders of systems, which operate within the space traffic control region, and builders of systems, which implement space traffic control, must provide highly reliable designs to meet the safety requirements.

SAFETY CONSIDERATIONS (CON'T.)

- SAFING/INERTING OF SYSTEMS AFTER DOCKING/BERTHING.

  1. PROPULSION SYSTEMS
  2. PYROTECHNIC SYSTEMS
  3. DEPLOYABLE APPENDAGES

- SCHEDULING OF VEHICLE/SYSTEM MANEUVERING IN VICINITY OF CREWMEN ON EVA.

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IMPLICATIONS OF SAFETY CONSTRAINTS

CONSTRAINT	OPERATOR PERSPECTIVE	USER PERSPECTIVE	BUILDER PERSPECTIVE
• SAFE STATIONKEEPING SEPARATION DISTANCES	• PREFER LARGE SEPARATION DISTANCES TO REDUCE "DENSITY" AND TIME CRITICALITIES	• PREFER SMALL SEPARATION DISTANCES FROM "MOTHER SHIP" TO MINIMIZE REVISIT COSTS AND TRANSFER TIMES	• COMMUNICATIONS & TRACKING CAPABILITIES AND DELTA-V CAPABILITIES DRIVEN BY SEPARATION DISTANCES.
• "SAFE" APPROACH CORRIDORS AND SEQUENCES.	• SERIAL BURNS WITH MINIMAL INTERCEPT POTENTIAL UNTIL FINAL BURN; WITH ADEQUATE TIME FOR SYSTEM CHECKOUT & VERIFICATION PRIOR TO FINAL BURN.	• LOW NUMBER OF BURNS TO REDUCE PHASING TIMES.	• HIGHLY RELIABLE GN&C, COMM & TRACKING, AND PROPULSION SYSTEMS.
• DEPARTURE CORRIDORS AND SEQUENCES	• INITIAL BURN SEQUENCES WHICH MINIMIZE "RETURN INTERCEPT" DUE TO DEGRADED PERFORMANCE.	• BURN SEQUENCES WHICH MINIMIZE TIME/PROPELLANT FOR TRANSFERS TO USER SYSTEMS.	• HIGHLY RELIABLE GN&C, COMM & TRACKING, AND PROPULSION SYSTEMS.
• PROVISIONS FOR MANUAL INTERVENTION	• OVERRIDE COMMAND AND CONTROL CAPABILITY OVER VEHICLES INCOMING TO A MANNED SYSTEM.	• LIMITED HARDWARE/SOFTWARE INTERFACES WITH EXTERNAL SYSTEMS FOR COMMAND AND CONTROL.	• SIGNIFICANT COMM & TRACKING AND COMMAND & CONTROL INTERFACES BETWEEN "CONTROLLING" ELEMENT AND ACTIVE SPACE VEHICLE.
• "SAFE" SEPARATION OF TETHERED PACKAGES.	• ACTIVE SYSTEM FOR CREATING OR MAINTAINING TENSION IN TETHER AND SEPARATION FORCES.	• MINIMUM COMPLEMENT OF HARDWARE/SOFTWARE IN TETHERED PACKAGE.	• HIGHLY RELIABLE REEL CONTROL AND TETHER "PROPULSION" SYSTEMS.

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IMPLICATIONS OF SAFETY CONSTRAINTS (CON'T.)

CONSTRAINT	OPERATOR PERSPECTIVE	USER PERSPECTIVE	BUILDER PERSPECTIVE
• DEBRIS MONITORING AND CONTROL	• TRACKING CAPABILITY FOR "DETECTABLE" DEBRIS IN SPACE TRAFFIC CONTROL AREA • PROCEDURES FOR MINIMIZE AMOUNT OF MAN-MADE DEBRIS IN TRAFFIC CONTROL AREA.	• DESIGNS AND OPERATIONS TO PRECLUDE DISCARDING OF MAN-MADE DEBRIS IN TRAFFIC CONTROL AREA.	• TRACKING SYSTEMS (GROUND AND ON-ORBIT) TO DETECT AND TRACK DEBRIS. • SYSTEM DESIGNS AND PROCEDURES TO MINIMIZE JETTISONED DEBRIS.
• "SAFE" STANDOFF DISTANCE FOR ON-ORBIT IGNITIONS.	• LARGE STANDOFF DISTANCES FROM MANNED SYSTEMS PRIOR TO BURN IGNITIONS.	• MINIMUM OPERATING TIMES FOR TRANSPORTATION AND LOGISTICS FLIGHTS TO USER SYSTEM.	• HIGHLY RELIABLE, LOW-THRUST SYSTEM FOR MANEUVERING TO STANDOFF POSITION. • HIGHLY RELIABLE, "MAIN" PROPULSION SYSTEMS.
• SAFING/INERTING OF SYSTEMS AFTER DOCKING/BERTHING.	• MONITOR CAPABILITY TO ASSURE THE SAFING & INERTING STATUS OF PROPULSION, PYROTECHNIC, AND DEPLOYABLE SYSTEMS FOR ATTACHED SPACE ELEMENTS. • OVERRIDE OR WAVEOFF CAPABILITY.	• INTERNAL PROCESSING FOR SAFING/INERTING AND RETRACTION WITH MINIMUM HARDWARE & SOFTWARE INTERFACES TO OTHER SYSTEMS.	• HIGHLY RELIABLE SAFING & INERTING AND RETRACTION SYSTEMS. • COMMAND & COMMUNICATIONS LINKS TO SUPPORT EXTERNAL MONITORING AND COMMAND OVERRIDE.
• SCHEDULING OF VEHICLE AND SYSTEMS MANEUVERS IN VICINITY OF EVAs.	• ALLOW NO OR EXTREMELY LIMITED AMOUNT OF VEHICLE MANEUVERING IN THE VICINITY, WHEN EVAs ARE BEING CONDUCTED.	• MINIMIZE THE CONSTRAINTS ON VEHICLE TRAFFIC DUE TO EVA OPERATIONS.	• PREDOMINATELY A SCHEDULING ISSUE, WHICH ONLY INDIRECTLY AFFECTS BUILDERS OF USER SYSTEMS.

CONSIDERATIONS OF ENVIRONMENTAL EFFECTS

- BLOCKAGE ENVELOPES
  - ORBITAL POSITION AND MANEUVER CONFIGURATIONS TO MINIMIZE:
    - A. "SHADOWING" OF COMMUNICATIONS AND TRACKING SYSTEMS
    - B. "SHADOWING" OF PAYLOAD/EXPERIMENT SENSORS
- PLUME IMPINGEMENT
  1. APPROACH CORRIDORS, SEQUENCES, AND EFFECTORS TO MINIMIZE IMPINGEMENTS ON FINAL BRAKING OR PROXIMITY MANEUVERS.
  2. ATTITUDE CONTROL MODES/EFFECTORS TO MINIMIZE IMPINGEMENTS DURING CLOSE VICINITY OPERATIONS
- CONTAMINATION
  1. SELECTION OF "NON-CONTAMINATING" PROPULSON AND CONTROL EFFECTORS
  2. LOCATION OF CONTAMINATION-SENSITIVE SYSTEMS AWAY FROM "HIGH TRAFFIC" AREAS.

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ENVIRONMENTAL EFFECTS

- The techniques for maneuvering under the space traffic control strategies should not result in adverse environmental impacts. Such impacts, which should be avoided, include:

  - Obstructing lines-of-sight for communications and tracking.
  - Obstructing lines-of-sight of payloads/experiments.
  - Damaging systems or payloads/experiments with plume impingements.
  - Contaminating payloads/experiments with by-products of propulsion/thruster systems.

IMPLICATIONS OF ENVIRONMENTAL EFFECTS CONSTRAINTS

CONSTRAINT	OPERATOR PERSPECTIVE	USER PERSPECTIVE	BUILDER PERSPECTIVE
• BLOCKAGE ENVELOPES	• PERIODIC COMM & TRACKING COVERAGE BETWEEN "MOTHER SHIP" AND SYSTEMS DURING STATIONKEEPING, WITH DISCRIMINATION AMONG INDIVIDUAL SYSTEMS. • 100% COMM & TRACKING COVERAGE BETWEEN "MOTHER SHIP" AND INCOMING, ACTIVE VEHICLE, DURING FINAL APPROACH.	• SCHEDULED COMM & TRACKING COVERAGE BETWEEN USER AND PAYLOAD OR EXPERIEMENT SYSTEM.	• BROAD CAPABILITY COMM & TRACKING SYSTEMS COVERING SPACE TRAFFIC CONTROL REGION AND SUPPORTING ALL TRAFFIC CONTROL FUNCTIONS.
• PLUME IMPINGEMENT	• DIRECTIONS, MAGNITUDES, AND TIMING OF FINAL BRAKING MANEUVERS SET TO MINIMIZE IMPINGEMENTS ON: "MOTHER SHIP" BY INCOMING ACTIVE VEHICLES OR ON SYSTEMS TO BE SERVICED BY TRANSPORTATION VEHICLES.	• MINIMUM IMPINGEMENTS ON USER FLIGHT SYSTEMS BY INCOMING TRANSPORTATION OR SERVICER VEHICLES.	• DEVELOPMENT OF ATTITUDE CONTROL MODES AND THRUSTER CONFIGURATIONS TO MINIMIZE IMPINGEMENTS DURING CLOSE VICINITY OPERATIONS.

IMPLICATIONS OF ENVIRONMENTAL EFFECTS CONSTRAINTS (CON'T.)

CONSTRAINT	OPERATOR PERSPECTIVE	USER PERSPECTIVE	BUILDER PERSPECTIVE
• CONTAMINATION	• MINIMIZE PROPULSION SYSTEM ACTIVITIES AND OTHER PARTICLE/GAS/FLUID EXPULSION ACTIVITIES IN VICINITY OF CONTAMINATION SENSITIVE SYSTEMS (ON "MOTHER SHIP" OR ON USER FLIGHT SYSTEMS.	• MINIMIZE THE CONTAMINATING ACTIVITIES IN VICINITY OF USER FLIGHT SYSTEMS.	• USE NON-CONTAMINATING PROPULSION AND CONTROL EFFECTORS AND/OR DIRECT CONTAMINATES AWAY FROM SENSITIVE SYSTEMS. • ARCHITECTURE DESIGNS TO SHIELD CONTAMINATION-SENSITIVE SYSTEMS OR LOCATE THEM AWAY FROM "HIGH TRAFFIC" AREAS.

DYNAMIC INTERACTIONS

- CONTACT DYNAMICS
  1. DOCKING/UNDOCKING AND BERTHING DYNAMICS ON "MOTHER SHIP"
  2. DOCKING/UNDOCKING DYNAMICS IMPARTED TO USER SYSTEM BY TRANSPORTATION AND SERVICING VEHICLE.
- CONTROL OF DOCKED/BERTHED CONFIGURATIONS
  1. CONTROL HANDOVER
  2. INITIAL DAMPING AND STABILIZATION
- IMPINGEMENT DYNAMICS
  1. ATTITUDE DESTABILIZATION DUE TO PLUME IMPINGEMENTS
- TETHERED DYNAMICS
  1. MOTHER SHIP/TETHERED PACKAGE DEPLOYMENT, SEPARATION MAINTENANCE, AND RETRACTION.
  2. TETHERED CONSTELLATION DEPLOYMENT, MAINTENANCE, AND REVISIT.

DYNAMIC INTERACTIONS

- Forces and torques will be transmitted between the two interacting systems during docking, undocking, and berthing. Such contacts are made between the mother ship and an incoming system or between a transportation/servicer vehicle and the user's system. These contact dynamics must be controlled within prescribed limits to maintain safety, structural integrity, controllability, and operating environments of the payloads/experiments. This will require the innovative development of docking techniques and mechanisms.

- Upon docking and berthing, there is a transition from a two-body problem with two active control systems to a single-body (but, perhaps, not rigidized configuration) problem with one active control system. The control techniques for the interacting systems must be integrated to assure acceptable performance.

- The dynamics imparted to the "passive" system in a docking maneuver, due to impingements must be controlled within acceptable limits. This is particularly true for the case of a transportation or servicer vehicle docking with a free-flying user system.

- The dynamics transmitted to the interconnected bodies by tethers must be controlled to insure integrity of the tether and stability in the separation of the bodies. It is desired to maintain these dynamics at low levels to preserve low-g operating environments in the tethered packages. Passive techniques (e.g., orbital mechanics and gravity-gradient effects) and active systems (reels and thrusters) may be required.

IMPLICATIONS OF DYNAMIC INTERACTION CONSTRAINTS

CONSTRAINT	OPERATOR PERSPECTIVE	USER PERSPECTIVE	BUILDER PERSPECTIVE
• CONTROLLED CONTACT DYNAMICS.	• MINIMIZE CONTACT DYNAMICS IMPARTED TO MOTHER SHIP DURING DOCKING/UNDOCKING AND BERTHING ACTIVITIES. • LIMIT CONTACT DYNAMICS IMPARTED TO FREE-FLYING USER VEHICLES DURING DOCKING AND SERVICING.	• LIMIT CONTACT DYNAMICS IMPARTED TO FREE-FLYING USER VEHICLES DURING DOCKING AND SERVICING TO PRECLUDE OVERSTRESSING STRUCTURE, PAYLOADS, OR APPENDAGES. • PREFER NOT TO RETRACT OR STOW APPENDAGES DURING DOCKING/SERVICING.	• ESTABLISH DOCKING TECHNIQUES, DESIGNS, AND MECHANISMS TO MEET DOCKING DYNAMICS CONSTRAINTS.
• CONTROL STABILIZATION DURING INITIAL DOCKING & BERTHING ATTACHMENT. • TWO-SYSTEM TO ONE-SYSTEM CONTROL AUTHORITY TRANSITION.	• SUFFICIENT CONTROL AUTHORITY WITHIN MOTHER SHIP OR SERVICER VEHICLE TO CONTROL DOCKED AND BERTHED CONFIGURATIONS, INCLUDING PRIOR TO RIGIDIZATION. • DEFINITIVE PROCESS AND TIMELINE FOR TRANSITION FROM TWO-SYSTEM CONTROL TO SINGLE-SYSTEM CONTROL, WITH OVERRIDE OR WAVE-OFF BY "PRIME" SYSTEM.	• RELIANCE ON MOTHER SHIP, MANIPULATOR, OR SERVICING VEHICLE TO PROVIDE STABILIZATION OF DOCKED CONFIGURATIONS. • LOW-PROBABILITY OF CONTINGENCY DEMATING AND REINSTATED CONTROL.	• STRUCTURAL STRENGTH AND DAMPING CHARACTERISTICS IN DOCKING/ATTACHMENT MECHANISMS. • CONTROL LAWS WHICH ACCOMMODATE LARGE MASS PROPERTIES CHANGES AND POTENITALLY "SOFT" INITIAL CONNECTIONS. • HIGHLY RELIABLE DOCKING, BERTHING, AND CONTROL SYSTEMS.

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IMPLICATIONS OF DYNAMICS INTERACTIONS CONSTRAINTS (CON'T.)

CONSTRAINT	OPERATOR PERSPECTIVE	USER PERSPECTIVE	BUILDER PERSPECTIVE
• LOW IMPINGEMENT DYNAMICS	• FINAL BRAKING DESIGNS AND TECHNIQUES TO MINIMIZE DYNAMIC DISTURBANCES DUE TO PLUME IMPINGEMENTS ON MOTHER SHIP OR SPACE SYSTEM BEING SERVICED.	• LOW PLUME IMPINGEMENTS ON USER'S SPACE SYSTEM TO MINIMIZE CONTROL AUTHORITY REQUIREMENTS ON USER'S SYSTEM.	• PROPULSION AND CONTROL SYSTEM DESIGNS AND DOCKING TECHNIQUES TO MINIMIZE POTENTIAL FOR PLUME IMPINGEMENTS.
• CONTROLLED DYNAMICS BETWEEN MOTHER SHIP AND TETHERED PACKAGE.	• TETHER REEL & "THRUSTER" SYSTEM, WHICH PROVIDE RELIABLE SEPARATION WITH LOW INTERACTIVE DYNAMICS.	• MINIMUM HARDWARE/SOFTWARE EQUIPMENT ON TETHERED PACKAGE.	• HIGHLY RELIABLE TETHER REEL AND THRUSTER SYSTEM DESIGNS.
• DEPLOYMENT, MAINTENANCE, & SERVICING OF TETHERED "CONSTELLATIONS"	• LOCATE TETHERED CONSTELLATIONS REMOTE FROM HIGH TRAFFIC AREAS. • MINIMAL SUPPORT FROM TRANSPORTATION/SERVICING SYSTEMS TO DEPLOY AND MAINTAIN CONSTELLATIONS. • MINIMIZE SERVICING REQUIREMENTS ON CONSTELLATIONS DUE TO COMPLEX APPROACH AND DOCKING TECHNIQUES.	• MINIMUM CONTROL REQUIREMENTS IMPOSED ON PACKAGES WITHIN TETHERED CONSTELLATION TO REDUCE HARDWARE & SOFTWARE AND INTERACTIVE DYNAMICS.	• TETHER REEL/THRUSTER DESIGNS TO DEPLOY AND MAINTAIN TETHERED CONSTELLATIONS. • MANEUVER/DOCKING TECHNIQUES FOR SERVICING ELEMENTS OF THE TETHERED CONSTELLATION.

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SERVICEABILITY CONSIDERATIONS

- RAPIDITY OF ACCESS

  1. STATIONKEEPING POSITIONING TO MINIMIZE TRANSIT AND PHASING TIME
  2. "TRAFFIC SCHEDULING"
  3. AVAILABILITY OF TRANSPORT SYSTEMS (E.G., OMV, OTV)

- EASE OF ACCESS

  1. ORBITAL POSITIONING TO MINIMIZE OBSTACLES AND COMPLEXITY OF RENDEZVOUS AND APPROACH PROCEDURES.
  2. LOCATION/CONFIGURATION OF DOCKING PORTS AND SERVICE PORTS
     - A. PREFER IN-PLANE MANEUVERS
     - B. AVOID PRECISION MANEUVERS AROUND OBSTACLES SUCH AS APPENDAGES, TETHERS, ETC.
  3. RETRACTION OF APPENDAGES

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SERVICEABILITY

- A prime requisite of the space traffic control strategies is high serviceability from the standpoint of both the users and the operators.

- In general, the User community would like to have rapid accessability to transportation and resupply, repair, and maintenance services, with reasonable costs. Since time generally translates into costs, the User community would prefer to have these services provided expeditiously. These desires must be tempered by: (1) safety constraints which establishes a preference for sequences of maneuvers with adequate time allowed to evaluate the current status, followed by approval for the next phase; and (2) a reasonable traffic rate and reasonable number of transportation/servicer vehicles in the fleet.

- From an Operator perspective, ease of access is a key ingredient to serviceability. "Clear" corridors for the space traffic control maneuvers are preferred. That is, the need to maneuver through a maze of deployed appendages and tethers and/or a high demand for out-of-plane maneuvers should be avoided. Achievement of this objective could require satellite configurations which locate the obstructions away from their docking or servicing ports or could require that the obstructions be retractable.

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IMPLICATIONS OF SERVICEABILITY CONSTRAINTS

CONSTRAINT	OPERATOR PERSPECTIVE	USER PERSPECTIVE	BUILDER PERSPECTIVE
• RAPIDITY OF ACCESS	• ESTABLISH REASONABLE LIMITS ON NUMBERS OF TRANSPORT/SERVICING VEHICLES TO BE CONTROLLED • FLIGHT RATES AND RESPONSE TIMES CONSISTENT WITH ONBOARD FLIGHT CREW CAPABILITIES. • MAINTAIN REASONABLE DENSITY IN TRAFFIC CONTROL REGIONS.	• HIGH PROBABILITY OF "ON TIME" TRANSPORTATION AND SERVICING. • "CLOSE" PROXIMITY TO MOTHER SHIP TO ALLOW SHORT TRANSIT TIMES. • CLUSTERING OF FREE-FLYERS TO "COST-SHARE" TRANSPORT AND SERVICING ACTIVITIES. • REASONABLY RAPID RESPONSE TIMES FOR CONTINGENCY SERVICES.	• "HIGH FUEL ECONOMY" DESIGNS TO LIMIT REFUELING REQUIREMENTS. • RAPID TURNAROUND CAPABILITIES TO MINIMIZE FLEET SIZE. • SYSTEM SIZING TO EFFECT COST EFFECTIVE TRANSPORTATION & SERVICING ACTIVITIES.
• EASE OF ACCESS	• LOW DENSITY IN TRAFFIC CONTROL REGIONS. • MINIMUM "OBSTACLES" IN APPROACH AND DEPARTURE CORRIDORS (E.G., ANTENNAS, TETHERS, SOLAR PANELS) • PREFERENCE FOR IN-PLANE MANEUVERS. • HIGH RELIABILITY IN ATTITUDE STABILIZATION OF "SERVICED" SYSTEM.	• MINIMUM IMPACT ON USER SYSTEM CONFIGURATION AND OPERATING MODES. • MINIMIZE NEED TO RETRACT OR STOW APPENDAGES PREPARATORY TO DOCKING OR SERVICING.	• CONFIGURATION DESIGNS WITH DOCKING & SERVICING PORTS LOCATED IN UNOBSTRUCTED AREAS, WITH PREFERENCE TO IN-PLANE ORIENTATION. • HIGHLY RELIABLE ATTITUDE CONTROL SYSTEMS IN "SERVICED" SYSTEMS. • CONTINGENCY TECHNIQUES FOR DOCKING/CAPTURE. • POTENTIAL FOR RETRACTABLE OR STOWABLE APPENDAGES ON SYSTEMS TO BE SERVICED.

CONSIDERATIONS OF RESOURCE UTILIZATION

- DELTA-V FOR ORBIT MAINTENANCE/STATIONKEEPING
  1. ORBITAL ALTITUDES
  2. RELATIVE SEPARATION DISTANCES
  3. "TUNING" OF BALLISTIC COEFFICIENTS OF CO-ORBITING BODIES
- DELTA-V FOR ORBIT TRANSFERS
  1. RELATIVE SEPARATION DISTANCES

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CONSIDERATIONS OF RESOURCE UTILIZATION

- A major contributor to the costs for transportation and servicing is the resource expenditure for these functions. The delta-V requirements comprise the bulk of these expenditures.

- From a User standpoint, lower orbital altitudes would reduce the delta-V requirements for transportation from the ground to the orbiting system. The obvious trade must be made against the atmospheric effects of the lower altitudes, which will raise the delta-V requirements for orbit maintenance.

- Similarly, small separation distances between orbiting systems would reduce the delta-V requirements for transit between these systems. However, smaller separation distances could require greater precision in the performance of stationkeeping, at the cost of delta-V.

- "Fare sharing", in which several "satellites" are visited during a round trip of a transportation/servicer vehicle, appears attractive to reduce the costs to individual users. However, design and cost trades must be performed to establish a reasonable capacity and "range" for transportation vehicles, which could service several satellites on a single round trip.

IMPLICATIONS OF RESOURCE UTILIZATION CONSTRAINTS

CONSTRAINT	OPERATOR PERSPECTIVE	USER PERSPECTIVE	BUILDER PERSPECTIVE
• DELTA-V FOR ORBIT MAINTENANCE/STATIONKEEPING.	• SET ALTITUDE FOR INTEGRATED ORBITAL OPS SUFFICIENTLY HIGH TO MINIMIZE AERO EFFECTS; BALANCED WITH GROUND-TO-ORBIT LAUNCH COSTS. • MAINTAIN LOW TRAFFIC DENSITIES AND HIGH RELATIVE SEPARATIONS TO REDUCE PRECISION IN STATIONKEEPING OPERATIONS.	• LOW PERFORMANCE ACCURACIES ON ORBIT MAINTENANCE AND STATIONKEEPING TO MINIMIZE CONSUMABLES USE AND DYNAMIC DISTURBANCES DUE TO THRUSTING FOR ORBIT MAKEUP OR STATIONKEEPING. • FEW LIMITATIONS ON USER SYSTEM ATTITUDE ORIENTATIONS/CONFIGURATIONS.	• DESIGN "FUEL ECONOMICAL" SPACE FLIGHT SYSTEMS. • CONSIDER "TUNING" OF BALLISTIC COEFFICIENTS OF CO-ORBITING BODIES.
• DELTA-V FOR ORBIT TRANSFERS	• BALANCE LOW DENSITY STATIONKEEPING AREAS WITH SHORT TRANSPORT DISTANCES FROM MOTHER SHIP. • ENCOURAGE FLIGHT PLANS WITH MULTIPLE SYSTEM SERVICING PER FLIGHT.	• ESTABLISH CLOSE VICINITY TO MOTHER SHIP TO MINIMIZE TIME AND TRANSPORTATION COSTS FOR SERVICING. • MINIMIZE DEDICATED FLIGHTS FOR SERVICING OF INDIVIDUAL USER SYSTEMS TO REDUCE COSTS TO EACH USER.	• DESIGN "FUEL ECONOMICAL" TRANSPORTATION VEHICLES. • ESTABLISH BALANCE OF TRANSPORTATION VEHICLE CAPACITY TO "TRAFFIC MODEL", FOR SHARED SERVICES.

4-34

SUMMARY/CONCLUSIONS

- THE DEVELOPMENT OF SPACE TRAFFIC CONTROL STRATEGIES IS A MAJOR CHALLENGE, SINCE THE REQUIREMENTS FROM THREE MAJOR SOURCES MUST BE INTEGRATED.
  - OPERATORS
  - USERS
  - BUILDERS

- A PROGRAM PLAN FOR SPACE TRAFFIC CONTROL IS NEEDED, WHICH CUTS ACROSS THESE FACTIONS AND THE MULTIPLE PROJECTS/PROGRAMS, WHICH WILL OPERATE IN THE SPACE TRAFFIC CONTROL REGION.

- THE PLAN SHOULD BE DEVELOPED EARLY TO <u>LEAD</u> THE EVOLUTION OF SPACE TRAFFIC CONTROL STRATEGIES. <u>REACTIONARY</u> APPROACH TO DEVELOPING SPACE TRAFFIC CONTROL STRATEGIES WILL RESULT IN PATCHWORK SYSTEM, WITH LOW EFFICIENCY AND HIGH COSTS.

TRW DEFENSE SYSTEMS GROUP

SUMMARY/CONCLUSIONS

- The requirements and constraints, which are derived from the Operators, Users, and Builders, represent significant challenges to the development of space traffic control strategies and system designs. These requirements and constraints are sometimes contradictory and reasonable compromises will have to be made to establish mutual accommodation.

- The number of different Users and User systems will add complications to the development of standard or uniform space traffic control policies. However, from the standpoint of costs and operational efficiency, it is not practical to custom design space traffic control policies for each individual user system.

- An early identification of the requirements and constraints, followed by systematic negotiations among the Operator, User, and Builder communities should be performed. Quantitative values for these requirements and constraints must be defined since they will form the major drivers for design and operational procedures. A program plan for space traffic control can then be developed, which takes into account the Operators, Users, Builders, and the multiple projects and programs (e.g., STS. Space Station, OMV, OTV, Space Platform, free-flyers), which will participate in space traffic control.

- Without a program plan, space traffic control policies will "evolve", based on the immediate, participating system(s). As additional systems enter the infrastructure, additional requirements and constraints will arise, which may or may not be consistent with previous policies. The resultant patchwork system could be expensive (e.g., retrofits) with limited accommodations for all the participants. A program plan should attempt to forecast requirements across a spectrum of potential participants and establish flexibility for "planned" evolution and technology infusion.

SUMMARY/CONCLUSIONS (CON'T.)

- AT THIS TIME, THERE ARE SIGNIFICANT ISSUES WHICH MUST BE RESOLVED AMONG THE THREE MAJOR FACTIONS:
  - OPERATORS WOULD PREFER LOW DENSITIES AND LOW TRAFFIC RATES, WITH SIGNIFICANT COMPLEMENT OF HARDWARE/SOFTWARE IN THE INTERACTING ELEMENTS TO INSURE COMMAND AND CONTROL CAPABILITES.
  - USERS WOULD PREFER HIGHLY RELIABLE AND HIGHLY RESPONSIVE TRANSPORTATION AND SERVICING SUPPORT, WITH MINIMAL ADDITIONAL HARDWARE/SOFTWARE ON THEIR SYSTEMS, WHICH ARE DEDICATED TO SPACE TRAFFIC CONTROL.
  - BUILDERS OF TRANSPORTATION/SERVICER VEHICLES, USER SYSTEMS, AND SPACE TRAFFIC CONTROL SYSTEMS MUST PROVIDE HIGHLY RELIABLE, FUEL ECONOMICAL, GOOD PAYLOAD DELIVERY CAPABILITIES.

SUMMARY/CONCLUSIONS (Con't.)

- Although the Operators, Users, and Builders will probably agree on the functional content of the major considerations for space traffic control, there are signficant issues regarding the weight assigned to each consideration and the degree to which accommodations must be made.

  - Operators will tend to place the highest weight on safety, which leads to a desire for low density and low traffic rates in the space traffic control region. In addition, Operators will desire to have good complements of equipment in the interacting systems to support communications and tracking and command and control between manned systems and unmanned systems, with high reliability.

  - Since the main objective of User systems are generally to support science and applications or commercial activities, Users would prefer to minimize the costs (dollars and weight) of hardware and software, which don't directly support these activities. Consequently, Users would desire a minimum of hardware, software, and operational procedures in their systems for space traffic control. In addition, the Users desire economical and responsive transportation and servicing capabilities, which has the potential for high densities and high traffic rates.

  - Builders must provide systems which satisfy the full range of the requirements and constraints. Significant trades will be required to strike a "happy medium" among the many requirements and constraints.

IMPACT OF TRANSPORTATION OPERATIONS ON SPACE STATION TRAFFIC LEVELS

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Houston, Texas
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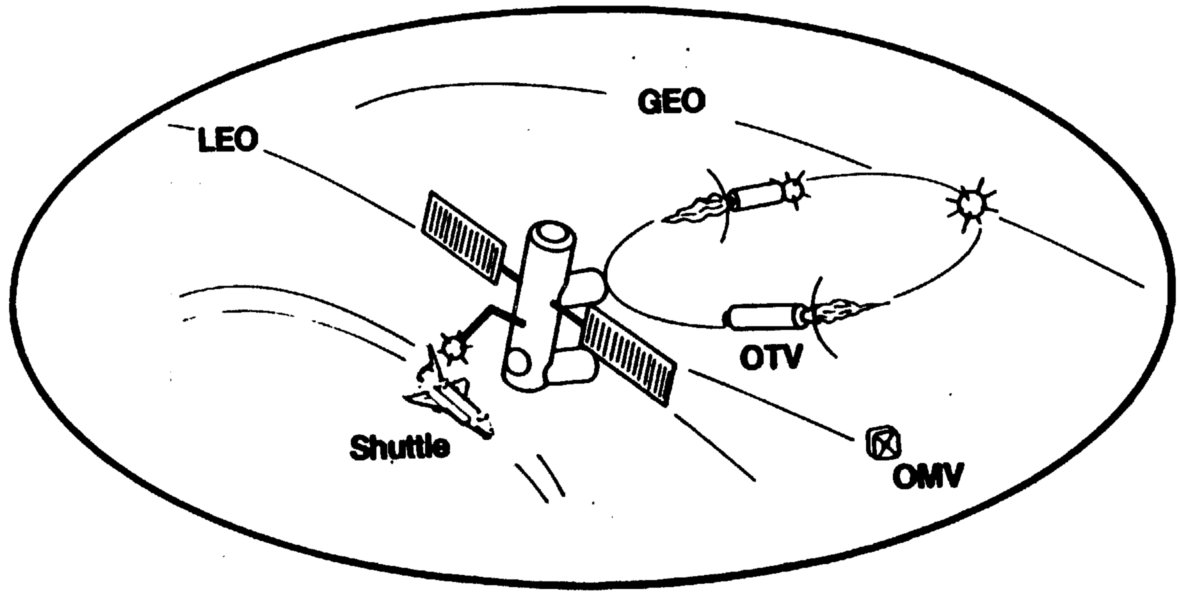
PROXIMITY OPERATIONS TRANSPORTATION ELEMENTS

The amount of traffic passing to and from a Space Station is a key issue for proximity operations, and it also figures prominently in the design of the station and space transportation elements. The Space Station must be designed to efficiently handle and service on-board payloads and to control vehicular traffic in its vicinity. The amount of traffic the station must control, and the number of vehicles it must support depends on the mission model, the turnaround capability of the transportation system, and the operational characteristics of the station. This presentation describes the analytical tools being developed to perform mission model and operational studies and presents the preliminary results relating operational complexity to mission model characteristics.

As a node in the space transportation system, the Space Station must perform numerous functions to support the various elements in the system. The elements include the Shuttle, used to deliver cargo to the station for support or dispersment; the orbital maneuvering vehicle (OMV), used for delivery and support in proximity of the station; and the orbital transfer vehicle (OTV), used to deliver geosynchronous orbit (GEO) and planetary bound payloads. To support these elements, the station must receive and process the cargo that the transportation system carries; maintain, fuel, and mate the vehicles with their cargo; and launch and receive each within the sphere of control defined by the station.

These activities place a number of demands on the station for support which are a function of operating strategies, technology levels, and traffic activity.

PROXIMITY OPERATIONS TRANSPORTATION ELEMENTS



Support	Space Station Requirements	Function Of
•Process cargo •Service P/LS •Maintain •Fuel •Mate •Launch •Receive •Storage	•Resources	•Operating strategies •Technology level •Traffic activity

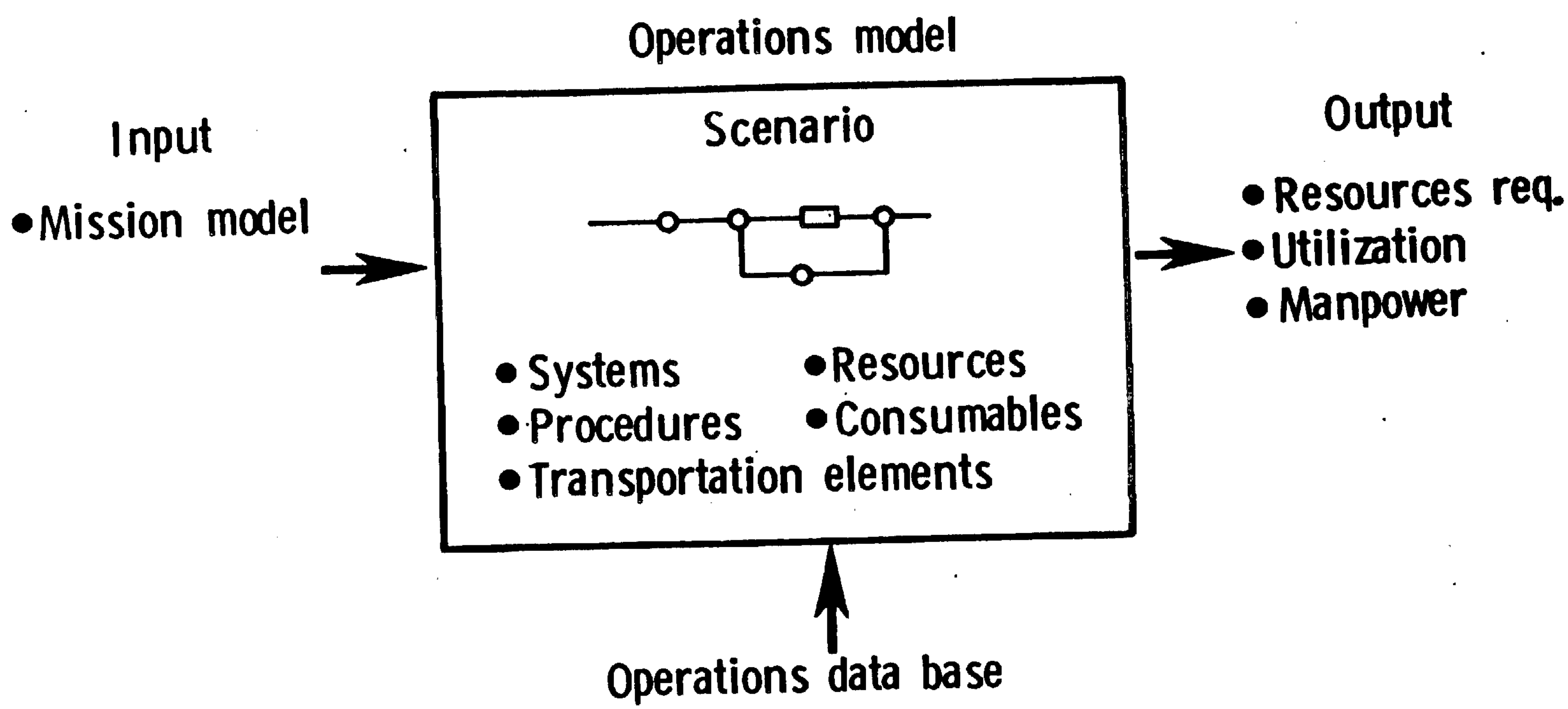
OPERATIONS ASSESSMENT

The purpose of this study is to determine the requirements placed on the station in terms of support equipment, manpower, and time. The quantity of support equipment such as manipulating arms for offloading and moving cargo, docking and maintenance facilities for the space-based elements, and propellant storage and refueling facilities should be a function of the technology levels of the transportation elements. This equipment, along with the transportation elements themselves, will require active support by the station crew members for maintenance, monitoring, launch, and retrieval operations. These requirements can be examined under conditions of improving technology levels and for alternate operational procedures in order to assess the effects of these changes. The results should indicate the effectiveness of these changes and point to areas of technology focus for maximum improvement in system effectiveness.

Since the mission requirements drive the level of activity at the station, the approach has been to first define a baseline mission model to use as a strawman. In addition, a simulation model is being developed to capture the integrated effects of the various activities at the station that are required to support the elements of the transportation system. The model, of course, focuses on the activity of these elements. Finally, the mission model is used to drive the model to simulate a period of activity at the station and to then compare those results with the results of other assessments requiring the same mission activity but with alternate technology or operating conditions being reflected in the model.

The scenarios developed should reflect the systems, procedures, and technologies that are to be examined. An operations data base is necessary to initialize the model with anticipated time and resource requirements that properly reflect the different technology levels that are assumed. The output is in the form of the quantity of support resources required to avoid delays because of conflicting demands for transportation and for manpower. These results can be compared with alternate scenarios to assess the effects of each.

OPERATIONS ASSESSMENT



BASELINE MISSION MODEL

In order to gain a perspective on the traffic level around the station and the mix of that traffic, a 10-year baseline mission model was developed. It was based largely on the Marshall Space Flight Center Mission Model (Revision 7). From it were drawn the logistic support requirements, the payloads designed to free fly in low-Earth orbit (LEO), those designed for geosynchronous Earth orbit (GEO), and the planetary missions. Added to this were payloads defined by the Space Station Mission Requirements Working Group as being attached to the station, but not requiring delivery beyond there. The model was adjusted to add additional GEO bound payloads in the latter years such that these requirements would not decrease during that time period as indicated by the Marshall model, but show a continued increase. The model does not include the propellant requirements for the OTV, the OMV, or for drag makeup of the station. As the propellant requirements are a function of technology levels and the procedure used, these are interactively defined by the use rate. The model contains no Department of Defense (DOD) payloads.

BASELINE MISSION MODEL

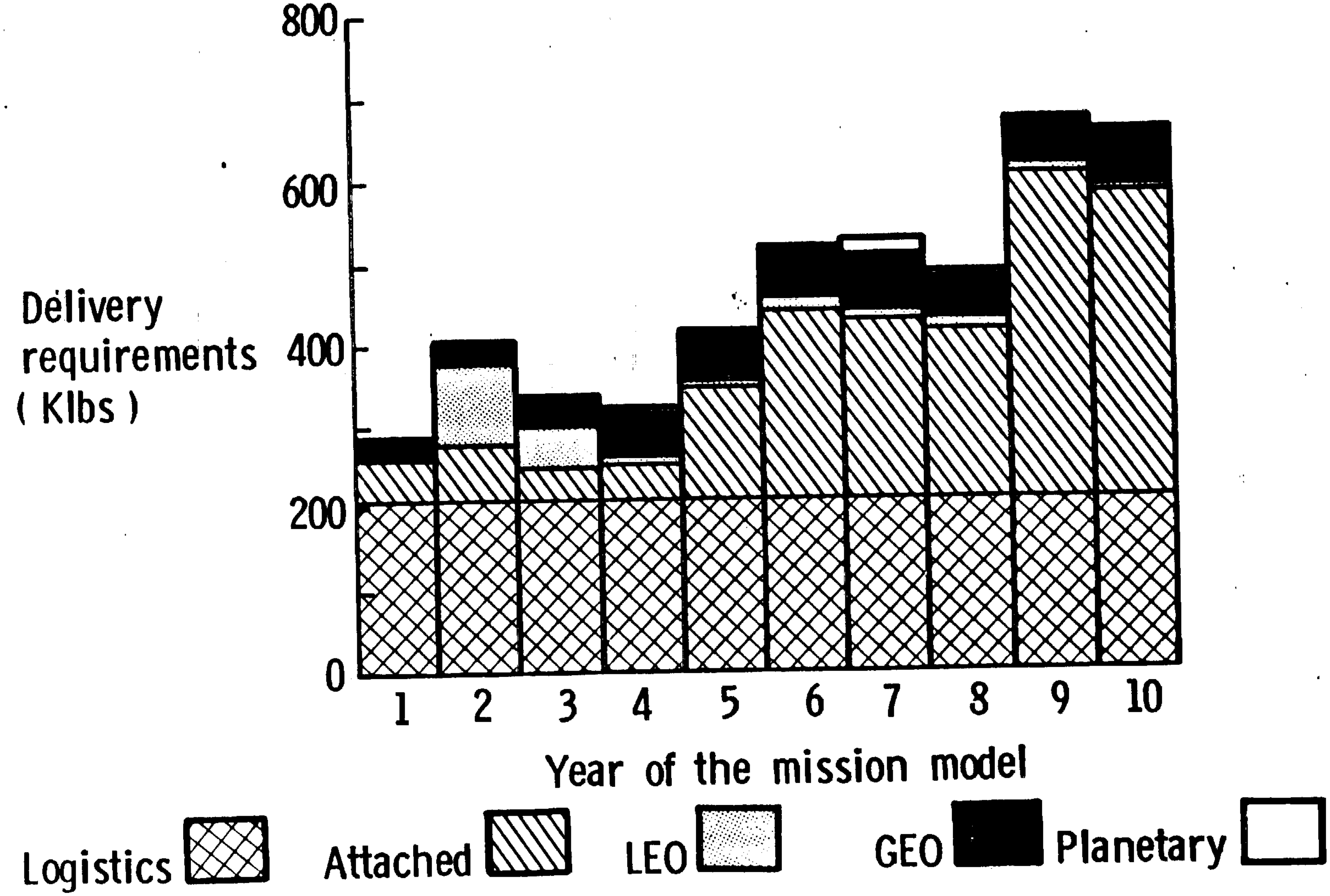
- Based on the Marshall Rev. 7 mission model
  - Logistics
  - LEO
  - GEO
  - Planetary
- Added space station mission requirements working group payloads
  - Attached
  - LEO
- Adjusted to add GEO missions
- Does not include propellant missions
- Does not include DOD missions

MISSION MODEL

The baseline mission model requires delivery of over 4.7 million pounds to the Space Station over a 10-year period. The maximum requirement is for nearly three quarter million pounds in the ninth year. The largest delivery requirement is the assumed eight logistic modules per year at 26,500 pounds each (excluding propellant delivery). Next in order are the attached payloads. The tonnage requirements, along with other payload characteristics and Shuttle distribution requirements dictate the number of flights required for delivery.

MISSION MODEL

(No propellant, no DOD)



MODELING APPROACH

A discrete event simulation language was chosen to model the transportation activities at the station because it will allow the capture of the interaction between the station and the elements that support the transportation system. This will allow the exploration of the operational capabilities of proposed systems and perhaps will influence the design choices to systems where the operations have been shown to be advantageous.

The flexibility of this modeling approach provides the ability to develop a top level model which can be used to study the overall flow of material through the transportation system, and/or to look at any component of the model in greater detail simply by defining the activities of that component in greater detail. A top level model might track the number of payloads delivered and time required to reach their destination, whereas a more detailed model might examine the turnaround processing of a space-based OTV. In either case, the systems can be used to study the flow of activities in the model in order to determine critical areas for the operations and gain a measure of the resources required to support them.

Models can be fairly easily modified to reflect alternate operational methods or new technologies, and the results can be used to evaluate the effectiveness of these changes. For example, the alternate operational methods might be used to look at different delivery techniques, or storage and handling of the propellants at the station, or the operational improvements because of using a new technology for propellant handling. The results of the comparison would be evaluated based on the manpower, time, and resource requirements of each alternative.

MODELING APPROACH

- Discrete event simulation
- Capture system interaction
- Expose critical areas
- Determine support requirements
- Modify and evaluate new systems

OPERATIONS MODEL

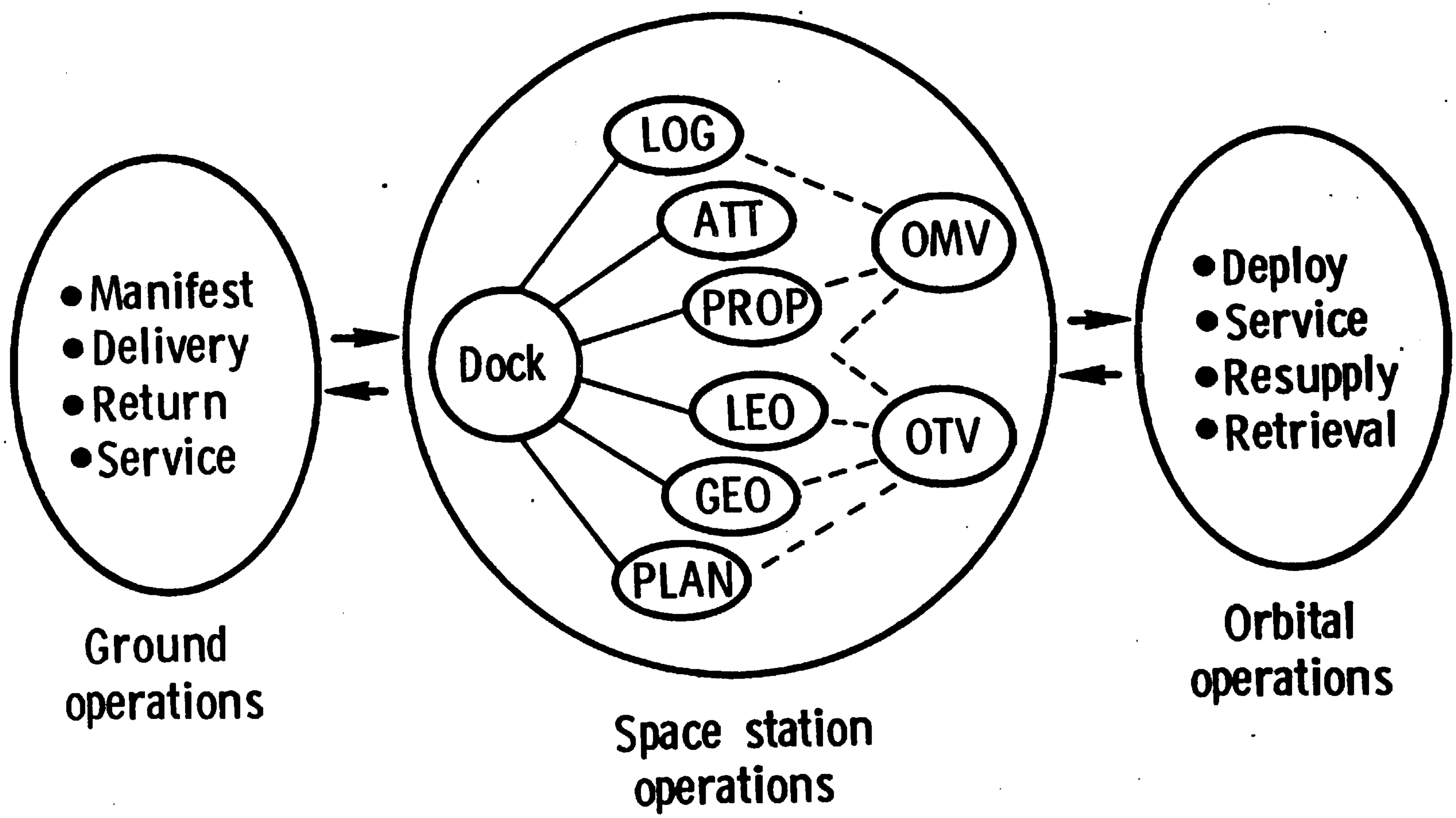
The operations model is designed to integrate the activities of all transportation elements in the system. It is composed of three sections: ground operations, Space Station operations, and orbital operations. The focus is on transportation activities during Space Station operations.

The ground operations include the manifesting of payloads from the mission model, delivery and docking activities, and return and service of the Shuttles. At this time, simple block times are used to define these activities.

The Space Station activities include the Shuttle docking and offloading of cargo at the station. Each payload is sorted and processed according to its use or destination. The attached (ATT) payloads are used in the station and do not require the transportation services beyond the station. The logistics (LOG) modules, the propellant (PROP) deliveries and payloads for low Earth orbit (LEO) may use the MRMS and/or the OMV for placement. Planetary (PLAN) and payloads destined for geosychronous orbit (GEO) would require the use of an OTV. It is in this manner that the demands are dynamically made of the system as the mission requirements dictate. This can lead to conflicts and delays in receiving resources or services which may be limited.

The orbital operations include deploying, servicing or resupplying, and/or retrieving satellites. The resupply and servicing are scheduled on deployment of the satellite and thus place an additional demand on the delivery system.

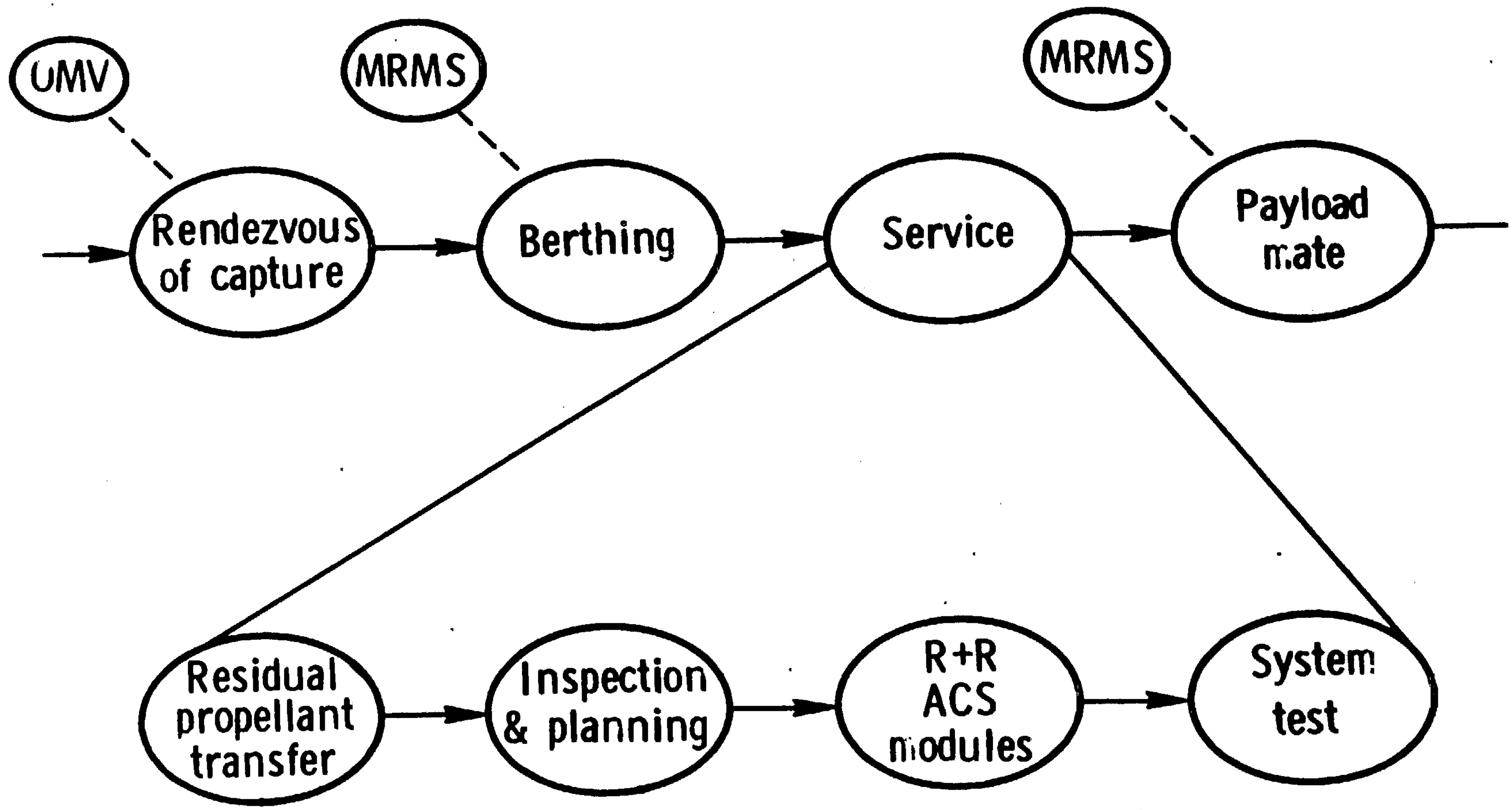
OPERATIONS MODEL



OTV SERVICE MODEL

As an example of the modeling level of detail, the OTV service model is illustrated. When an OTV returns to the proximity of the Space Station from GEO, an OMV is used to rendezvous with and capture it. At the station, a mobile remote manipulating system (MRMS) is required for berthing the OTV. The service time can be treated as a single block of time or expanded to include additional detail such as the propellant transfer, inspection and planning, remove and replace (R&R) the atitude control system (ACS) modules, and systems test time requirements. This modeling level may be required to study the effects of alternate technologies in service operations. Once serviced, the OTV is available for mating with a payload or cargo for the flight to GEO.

OTV SERVICE MODEL



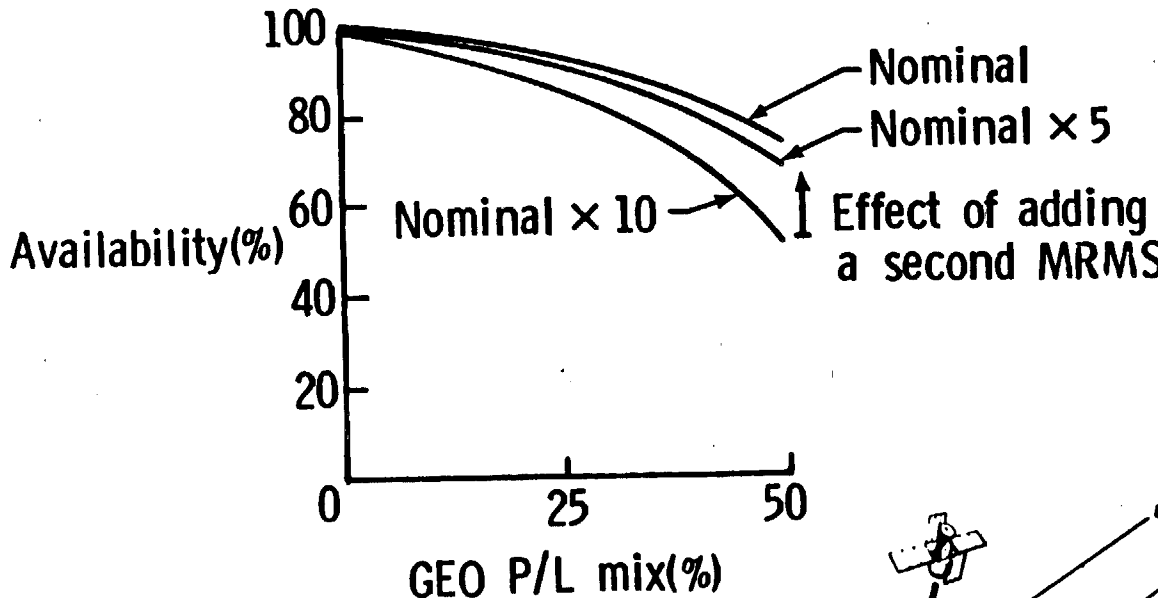
AVAILABILITY EXAMPLE

As an example, the availability for additional flights of a station based OTV was examined for three scenarios which reflected increases in the service time requirements. A nominal service or turnaround time was assumed then increased up to 10 times to reflect the effects of extended service activity. These were examined over a 1-year period for a mix of 60 payloads delivered to the station. From 1/8 to 1/2 of these payloads required delivery to GEO and the use of an OTV. Manifesting reduced this to only two to eight flights for the year. The results indicate that the availability of the OTV decreases more rapidly than might be expected purely from the time allotted for payload delivery and for servicing. In these cases, the additional time required to process and deploy the OTV is due, in part, to delays in receiving the MRMS. This piece of support equipment is needed to support several different activities that can occur concurrently. When not available, the support equipment limits the availability of the OTV by delaying the service.

The interdependence of all transportation elements and their support requires that their operations not be studied as an independent activity, but reflect the dependency of these major elements. Presently, only the MRMS and OMV are included in the model in support of OTV activity. Manpower and traffic control are two additional areas that are to be added. Manpower requirements are a major support element that is central to the availability of all of the transportation elements and by establishing the level of support required for transportation, can provide a needed input to Space Station crew requirements.

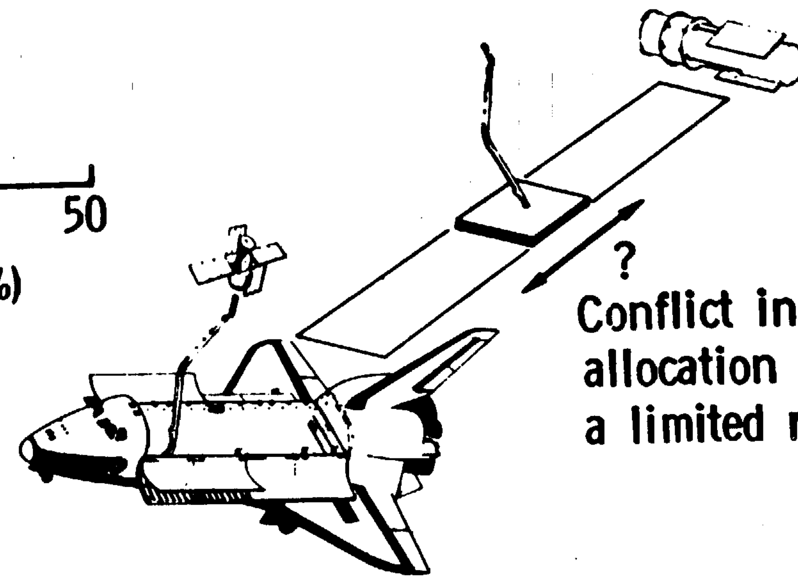
Proper modeling of operations at the station will require not only a definition of the procedures and time requirements, but also a set of rules by which conflicts can be resolved when there are multiple demands on a limited resource. In the case of the OTV and the Shuttle delivery, which has priority: offloading the payload or berthing an OTV which has returned? Scheduling can avoid many of these conflicts, but when they do occur, a policy for resolution must be established. The process of modeling these operations forces the need for these choices to be recognized and dealt with early in conceptual design.

AVAILABILITY EXAMPLE



Support Elements

- MRMS
- OMV
- Manpower
- Control (traffic)



ALTERNATE DELIVERY SCENARIOS

As an example of the types of traffic levels anticipated, a matrix of options have been examined analytically in which two different delivery options and four different OTV types were used to determine the effect on traffic levels. The alternate delivery strategies used two different scenarios to deliver material to a Space Station.

The direct delivery scenario assumes direct insertion of the orbiter to the Space Station followed by a hard dock operation prior to offloading the cargo. The direct insertion to station altitude limits cargo capacity to 61,500 pounds (based on a lightweight external tank, filament wound SRB motors, and 109 percent SSME power level).

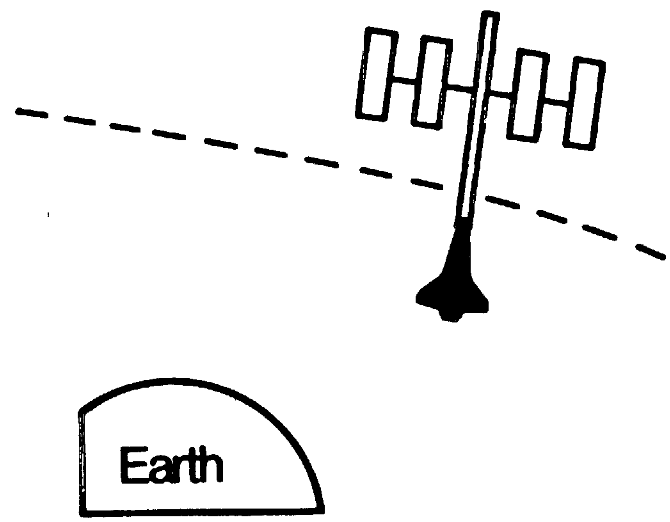
The remote delivery scenario requires the Shuttle to achieve an altitude of only 160 n.mi. and the OMV to then ferry the cargo to the Space Station. This lower altitude allows a higher cargo capacity for the Shuttle (72,500 pounds), but involves a tradeoff with increased OMV utilization, fuel, and maintenance requirements.

In all cases, a manifesting of Shuttle payloads takes place which assumes a 65 percent average load factor and a maximum of 4 payloads per flight. The number of Shuttle flights required for delivery to the station were not considered to be constrained by launch facilities. The OTV's were also manifested at the station assuming a 20,000-pound capacity, a maximum length of 50 feet, and a maximum of 4 payloads per flight. Payloads designated as LEO free flyers were single manifested on the OTV.

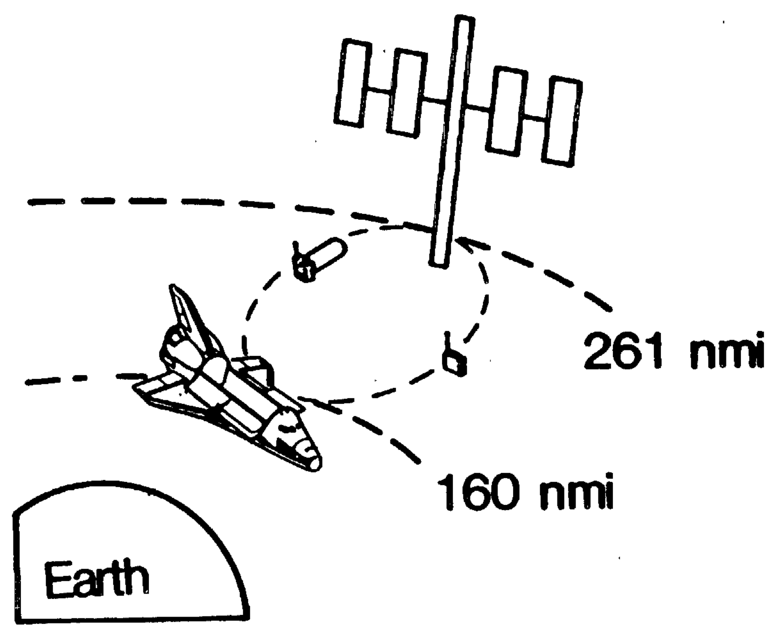
ALTERNATE DELIVERY SCENARIOS

(Filament wound HPM, 109% SSME power level)

- **Direct**
  - Hard dock
  - 61500 lb



- **Remote**
  - OMV ferry
  - 72500 lb



DIRECT DELIVERY TRAFFIC LEVEL

A direct delivery scenario for delivery to the station is illustrated in terms of the traffic load and vehicle utilization for a current technology OTV (all propulsive, 459 Isp). For this scenario, a total of 294 Shuttle missions are required of which 116 (or 40 percent) are for propellants. This scenario represents a maximum one-year peak of 38 Shuttle flights.

In the proximity of the station, there were 91 OTV flights (18 percent of the total activity at the station) and 113 OMV flights (26 percent) in addition to the 294 Shuttle flights (56 percent). This represents a total of 518 flight events at the station over the life of the mission model, peaking at 69 events per year in the last 2 years. (Note: An event represents both the launch and retrieval process).

DIRECT DELIVERY TRAFFIC LEVEL

Number of flight events

	Trans. element \ Yr.	1	2	3	4	5	6	7	8	9	10	Total
STS delivery mix	Mission model	12	15	14	14	17	20	20	18	24	24	178
STS delivery mix	Propellant	8	6	10	13	11	12	16	13	14	13	116
	STS	20	21	24	27	28	32	36	31	38	37	294
	OTV	6	5	8	10	9	10	12	10	11	10	91
	OMV	6	7	8	10	12	14	16	18	20	22	133
	Total	32	33	40	47	49	56	64	59	69	69	518

REMOTE DELIVERY TRAFFIC LEVEL

In using the remote delivery scenario, a tradeoff is established which reduces the number of Shuttle flights to the station (and increases the delivery capacity of the Shuttle) but increases the number of OMV flights. The total number of Shuttle flights is reduced to 270 of which only 40 are considered to be delivered directly to the station for crew exchange and logistic support. The remaining 230 utilize the OMV to ferry the cargo to the station. This represents a total of 494 flight events at the station of which 91 are OTV flights (18 percent of the total activity at the station), 363 are OMV flights (74 percent), and only 40 are Shuttle flights (8 percent). The peak Shuttle flight rate is reduced to 34 flights per year using remote delivery. This option might be utilized to reduce flight requirements should launch capacity be a limiting factor.

The 24 event reduction derived by using the remote delivery technique also represents a change in the mix of vehicles active at the station. If the support required to actively control the OMV is less than that required of the Shuttle, then this could represent a savings both in STS flights and in Shuttle support.

REMOTE DELIVERY TRAFFIC LEVEL

Number of flight events

	Trans. element \ Yr.	1	2	3	4	5	6	7	8	9	10	Total
STS delivery mix	Mission model	11	14	13	14	15	17	18	17	22	22	163
STS delivery mix	Propellant	7	6	9	12	11	11	14	12	13	12	107
	STS(OMV)	14	16	18	22	22	24	28	25	31	30	230
	STS(STA)	4	4	4	4	4	4	4	4	4	4	40
	OTV	6	5	8	10	9	10	12	10	11	10	91
	OMV	20	23	26	32	34	38	44	43	51	52	363
	Total	30	32	38	46	47	52	60	57	66	66	494

EFFECT OF OTV TECHNOLOGY OPTIONS ON SHUTTLE FLIGHTS

The option of using advanced technology for the OTV was also examined to assess the effectiveness of these improvements. These changes would not alter the number of OTV flights since these are based on the manifest requirements, but would be reflected in the number of Shuttle flights required for support. Four combinations of both improved engine technology and the use of aerobraking were examined for the direct and remote delivery options.

Although the largest reduction in flights occur by using both the aerobraking and the higher technology engine, over 80 percent of this reduction could be achieved by using aerobraking alone with present engine technology levels.

All of these strategies and technology improvements represent reduced flight rates both to and at the station, and thus should reduce the traffic control load that the station must support. However, not addressed at this time is a possible increase in support activities required of the Space Station resources and crew for the maintenance activities created by these options. These must be addressed before improvements in system effectiveness can be accurately assessed.

EFFECT OF OTV TECHNOLOGY OPTIONS ON SHUTTLE FLIGHTS

	Delivery mode	
OTV Technology level	Direct	Remote
All propulsive, ISP= 459	294*	270
All propulsive, ISP= 482	280	257
Aerobraking, ISP= 459	258	239
Aerobraking, ISP= 482	251	232

*Number of shuttle flights required to complete mission model

CONCLUDING REMARKS

Proximity operations flight activity levels at the Space Station have been developed for two different operating scenarios based on a 10-year mission model. The results indicate a total activity level on the order of 500 events with a maximum of 69 events per year. Approximately 40 percent of the Shuttle traffic represents propellant delivery. In the proximity of the station, 18 percent of the traffic is generated by the OTV flights. The OMV activity varies from 26 percent to 74 percent and the Shuttle from 8 percent to 56 percent of the total depending on the delivery mode. The traffic burden in the proximity of the station can be reduced based upon the delivery procedures used and/or the technology options chosen for use on the OTV's.

The maximum flight rates represent an event every five days on average but do not address the effects of the clustering of events. Modeling activities will be needed to address the dynamics of traffic in the proximity of the station in which the demand for station support may exceed capacity and create dalays. Realistic input data will be needed to support these modeling activities so that total system effectiveness can be assessed.

CONCLUDING REMARKS

- Flight activity levels in proximity of the space station have been derived for a 10 year period
- Total activity level ~ 500 events
- Maximum one year 69 events
- 40% Shuttle flights propellant delivery
- Traffic burden at the station can be reduced based on
  - Procedures
  - Technology options
- Modeling needed to address the dynamics of traffic flow

OPERATIONAL CONTROL ZONES

BLAIR A. NADER
A. L. DUPONT

AGENDA

- THE QUESTION
- USER REQUIREMENTS
- SPACE STATION OPERATIONAL OBJECTIVES
- SPACE STATION OPERATIONAL ASSUMPTIONS
- AN ANSWER
- IMPACTS TO DATE
- CONCLUSIONS

THE QUESTION: HOW DO WE COORDINATE MULTIPLE ON-ORBIT OPERATIONS IN THE VICINITY OF THE SPACE STATION?

- MANY ELEMENTS WILL OPERATE NEAR THE SPACE STATION
  - STS ORBITER (S)
  - ORBITAL MANEUVERING VEHICLE(S) (OMV'S)
  - ORBITAL TRANSFER VEHICLE(S) (OTV'S)
  - SPACE PLATFORM(S)
  - CO-ORBITING SATELLITE(S)
  - NON-CO-ORBITING SATELLITE(S)
  - MANNED MANEUVERING UNIT(S) (MMU's)
  - EVA CREWMEMBER(S)
- THESE SPACE STATION ELEMENTS WILL PERFORM MANY OPERATIONS INCLUDING:
  - RENDEZVOUS
  - APPROACHES
  - FLYAROUNDS
  - SEPARATIONS
  - ORBITKEEPING

USER REQUIREMENTS ON THE SPACE STATION

- SPACE STATION SYSTEM IS REQUIRED TO PROVIDE SEVERAL SERVICES TO ITS USERS INCLUDING:
  - LOW-GRAVITY ENVIRONMENT
  - COMMUNICATIONS
  - OPTIONAL MANNED MONITORING OF EXPERIMENTS
  - SERVICING/RESUPPLY OF MANUFACTORING FACILITIES, PLATFORMS, CO-ORBITING AND NON-CO-ORBITING SATELLITES
- SPACE STATION USERS CAN HAVE CONFLICTING REQUIREMENTS
  - e.g.: FREQUENT SERVICING AND LOW-GRAVITY ENVIRONMENT
  - e.g.: MANNED SERVICING AND "HIGH" OPERATING ALTITUDES (NON-CO-ORBITING SATELLITES)

SPACE STATION OPERATIONAL OBJECTIVES

- MULTIPLE DETACHED OPERATIONS MUST ADDRESS THE FOLLOWING OPERATIONAL OBJECTIVES:
  - STANDARDIZED FLIGHT PLANNING AND OPERATIONS
  - STANDARDIZED CREW PLANNING AND OPERATIONS
  - EARLY DEFINITION OF FLIGHT REQUIREMENTS
  - COLLISION AVOIDANCE
  - REDUCED PLUME IMPINGEMENT/CONTAMINATION TO THE SPACE STATION
  - REDUCED USE OF THE CREW IN ROUTINE TASKS

SPACE STATION OPERATIONAL ASSUMPTIONS

- INITIALLY, THE SPACE STATION IS NOT AUTONOMOUS
- THE GROUND WILL HANDLE FLIGHT PLANNING, TRACKING, AND CONTROL FOR ALL TRAFFIC UNTIL ACTIVE CREW INVOLVEMENT IS REQUIRED
- THE SPACE STATION CREW WILL MONITOR ALL ACTIVE FLIGHT OPERATIONS OCCURING WITHIN AT LEAST 37 KM (20 N.MI.)
  - MANUAL OVERRIDE CAPABILITY MUST EXIST ON THE SPACE STATION FOR UNMANNED VEHICLES
- THE GROUND WILL HAVE PRIMARY CONTROL OF CO-ORBITING SATELLITES
  - SATELLITES WILL BE MAINTAINED IN APPROXIMATELY THE SAME ORBIT AND PLANE AS THE SPACE STATION
  - THE SATELLITE-TO-STATION SEPARATION RANGE IS A FUNCTION OF THE SATELLITE'S REQUIRMENTS ON THE SPACE STATION

SPACE STATION OPERATIONAL ASSUMPTIONS (CON'T)

- THE GROUND WILL HAVE PRIMARY CONTROL OF NON-CO-ORBITING SATELLITES
  - SATELLITES NEED NOT ACTIVELY ORBITKEEP RELATIVE TO THE SPACE STATION
  - ORBITAL PLACEMENT DETERMINED BY SATELLITE REQUIREMENTS (E.G., FAVORABLE RELATIVE ORBIT PLANE FOR SERVICING) AND COLLISION AVOIDANCE
- A PARKING ORBIT WILL BE ALLOCATED FOR VEHICLES RETURNING, FROM HIGH ENERGY ORBITS.
- THE ORBITER WILL NOT IMPOSE ANY REQUIREMENTS UPON THE SPACE STATION EXCEPT FOR BERTHING

AN ANSWER: THE OPERATIONAL CONTROL ZONE CONCEPT

NINE ZONES HAVE BEEN ALLOCATED TO SUPPORT SPACE STATION TRAFFIC CONTROL ACTIVITIES

ZONE	FUNCTIONS
1	PROXIMITY OPERATIONS ZONE (BERTHING, PROXIMITY OPERATIONS)
2	COMMAND AND CONTROL ZONE (ACTIVE SPACE STATION TRAFFIC MONITORING, ETC)
3	DEPARTURE ZONE (OTV, OMV)
4	RENDEZVOUS ZONE (STS, OTV, OMV)
5	CO-ORBITING ZONE (LEADING)
6	CO-ORBITING ZONE (TRAILING)
7	NON-CO-ORBITING ZONE (LOWER)
8	NON-CO-ORBITING ZONE (UPPER)
9	PARKING ORBIT ZONE (OTV, OMV, ETC.)

IMPACTS OF THIS CONCEPT TO DATE

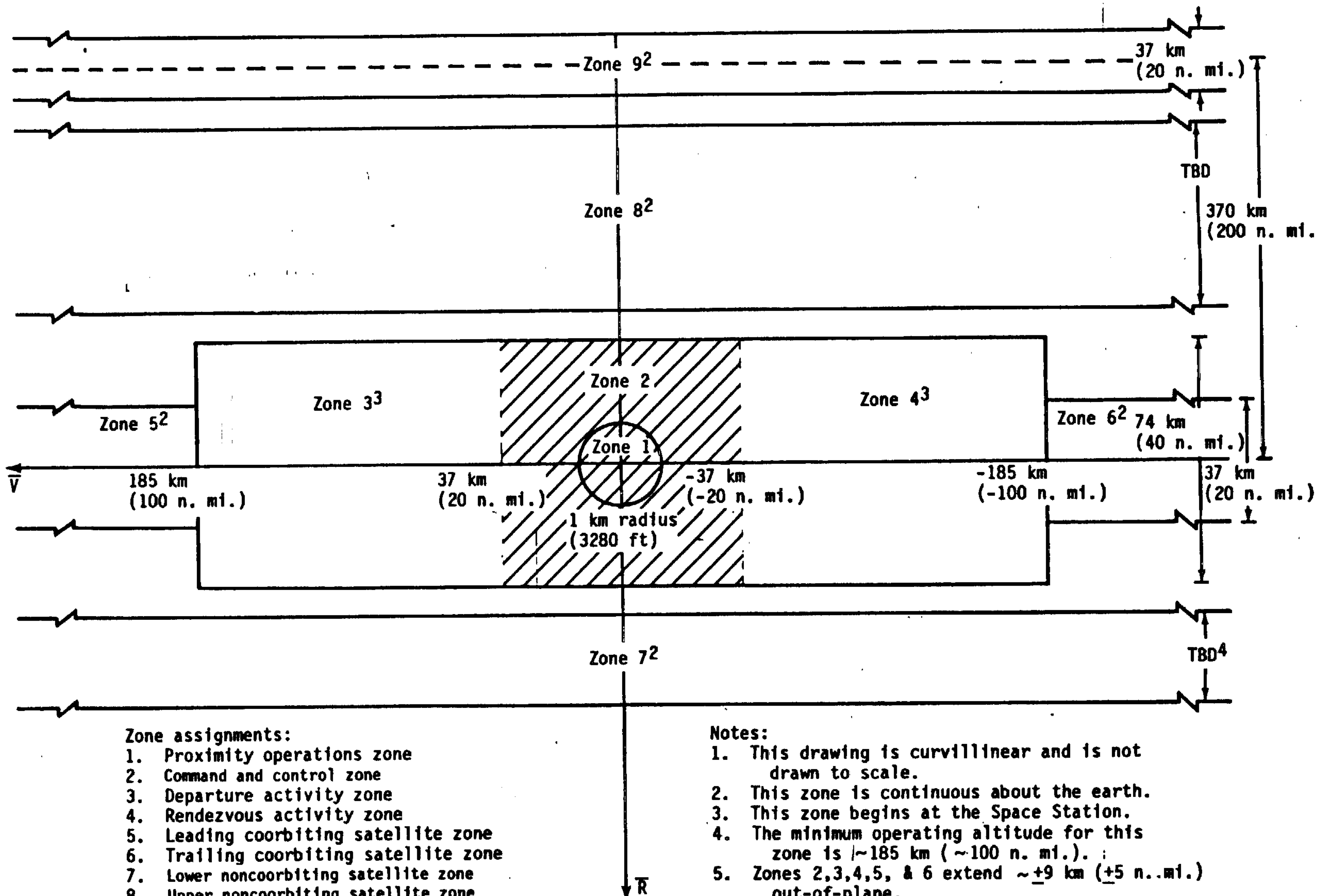
- IT HAS BEEN USED TO ASSIST INITIAL DEFINITION OF SPACE STATION COMMUNICATION AND TRACKING REQUIREMENTS
- IT HAS BEEN PUBLISHED IN THE FOLLOWING:
  - SPACE STATION OPERATIONS: OPERATIONAL CONTROL ZONES
    - MISSION PLANNING AND ANALYSIS DIVISION INTERNAL NOTE
  - CONCEPTUAL DESIGN AND EVALUATION OF SELECTED SPACE STATION CONCEPTS, DECEMBER 1983
    - JSC SPACE STATION PROGRAM OFFICE
  - SPACE STATION REFERENCE CONFIGURATION DESCRIPTION, AUGUST 1984
    - SE & I, SPACE STATION PROGRAM OFFICE
  - SPACE STATION OPERATIONS PLAN; BASIC, SEPTEMBER1, 1984
    - MISSION OPERATIONS DIRECTORATE

IMPACTS OF THIS CONCEPT TO DATE (CON'T)

- FREE-FLYER MISSION SUPPORT FROM A SPACE STATION VOLUME II: ORBITAL MANEUVERING VEHICLE (OMV) FLIGHT PROFILES
  - MISSION PLANNING AND ANALYSIS DIVISION INTERNAL NOTE (PUBLICATION PENDING)
- SPACE STATION OPERATIONS VOLUME III: PROXIMITY OPERATIONS
  - MISSION PLANNNG AND ANALYSIS DIVISION INTERNAL NOTE (PUBLICATION PENDING)
- IT HAS BEEN INCORPORATED INTO SPACE STATION SIMULATIONS
  - eg: ORBITAL OPERATIONS SIMULATOR (OOS)

CONCLUSIONS

- THE OPERATIONAL CONTROL ZONE CONCEPT WILL PROVIDE A CONSISTENT FOUNDATION AND AN INTEGRATED FRAMEWORK FOR DEVELOPMENT AND CONDUCT OF SPACE STATION OPERATIONS
  - ASSIST IN AN EARLY DEFINITION OF REQUIRMENTS
  - ASSIST STANDARDIZATION OF CREW TRAINING AND OPERATIONS
  - ASSIST STANDARDIZATION OF MOST RENDEZVOUS AND PROXIMITY OPERATIONS PROFILES AND PROCEDURES
  - ASSIST IN MONITORING AND COLLISION AVOIDANCE (I.E., A-PRIORI KNOWLEDGE OF TARGET LOCATION)
- A HIGH PRIORITY MUST BE GIVEN TO TASKS RELATED TO MATURING THE DETAILS OF THIS CONCEPT
  - THE CONCEPT LACKS FULL MATURITY
  - THE CONCEPT IS INTIMATELY RELATED TO DESIGN OF THE SPACE STATION AND ITS ELEMENTS



Zone assignments:
1. Proximity operations zone
2. Command and control zone
3. Departure activity zone
4. Rendezvous activity zone
5. Leading coorbiting satellite zone
6. Trailing coorbiting satellite zone
7. Lower noncoorbiting satellite zone
8. Upper noncoorbiting satellite zone
9. Parking orbit zone

Notes:
1. This drawing is curvilinear and is not drawn to scale.
2. This zone is continuous about the earth.
3. This zone begins at the Space Station.
4. The minimum operating altitude for this zone is ~185 km (~100 n. mi.).
5. Zones 2,3,4,5, & 6 extend ~± 9 km (± 5 n. mi.) out-of-plane.
6. Zones 7,8 and 9 are spherical shells centered about the Earth.

Figure 1.- Operational control zones.[1]

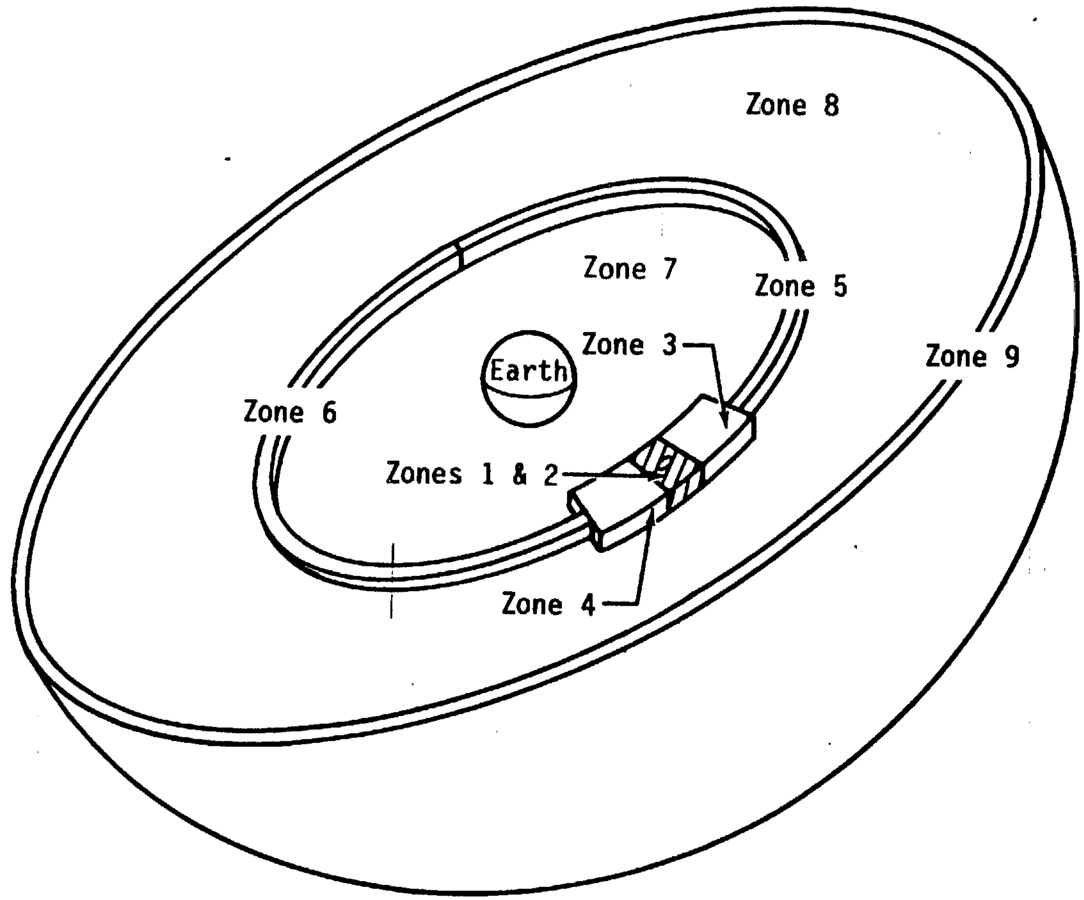


Figure .- Cutaway view of operational control zones (hemispherical cutaway).

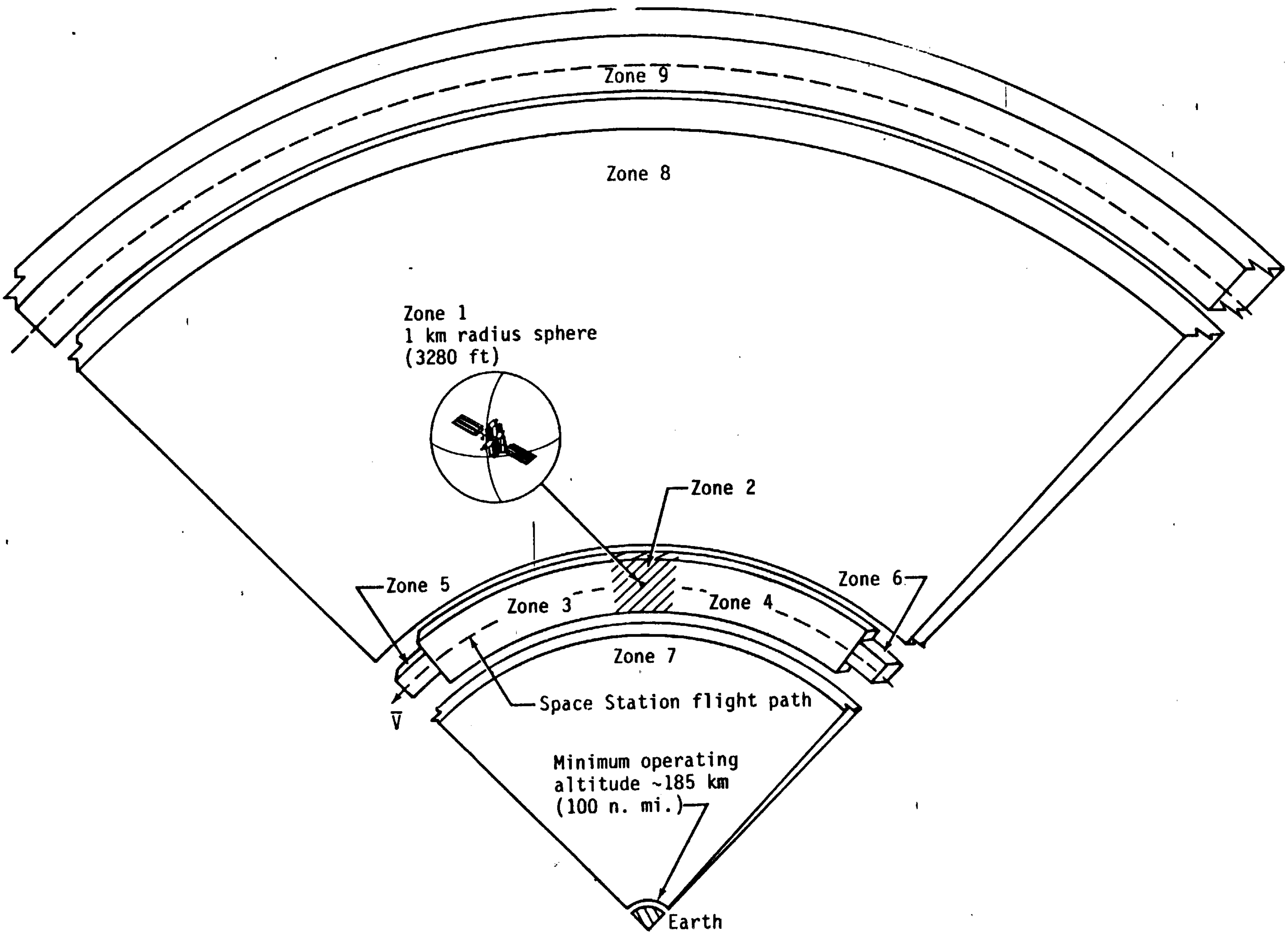


Figure .- Scale drawing of operational control zones in 3 dimensions.

PROXIMITY OPERATIONS ANTENNA PATTERN COVERAGE FOR SPACE STATION TRAFFIC CONTROL

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PRESENTED

RENDEZVOUS AND PROXIMITY OPERATIONS WORKSHOP

FEBRUARY 19-22, 1985

PROXIMITY OPERATIONS ANTENNA PATTERN COVERAGE FOR SPACE STATION CONTROL

- OBJECTIVE AND JUSTIFICATION
- AREAS OF STUDY
  - OBSCURATIONS
  - MULTIPATH EFFECTS
  - ANTENNA PATTERN COVERAGE
- METHODOLOGY
  - RAY TRACING APPROACH
  - SCATTERING THEORY APPROACH (GTD)
- RESULTS AND DISCUSSION
- CONCLUSIONS AND RECOMMENDATIONS

ANTENNA PATTERN COVERAGE AND BLOCKAGE EFFECTS FOR SPACE STATION TRAFFIC CONTROL

OBJECTIVE :

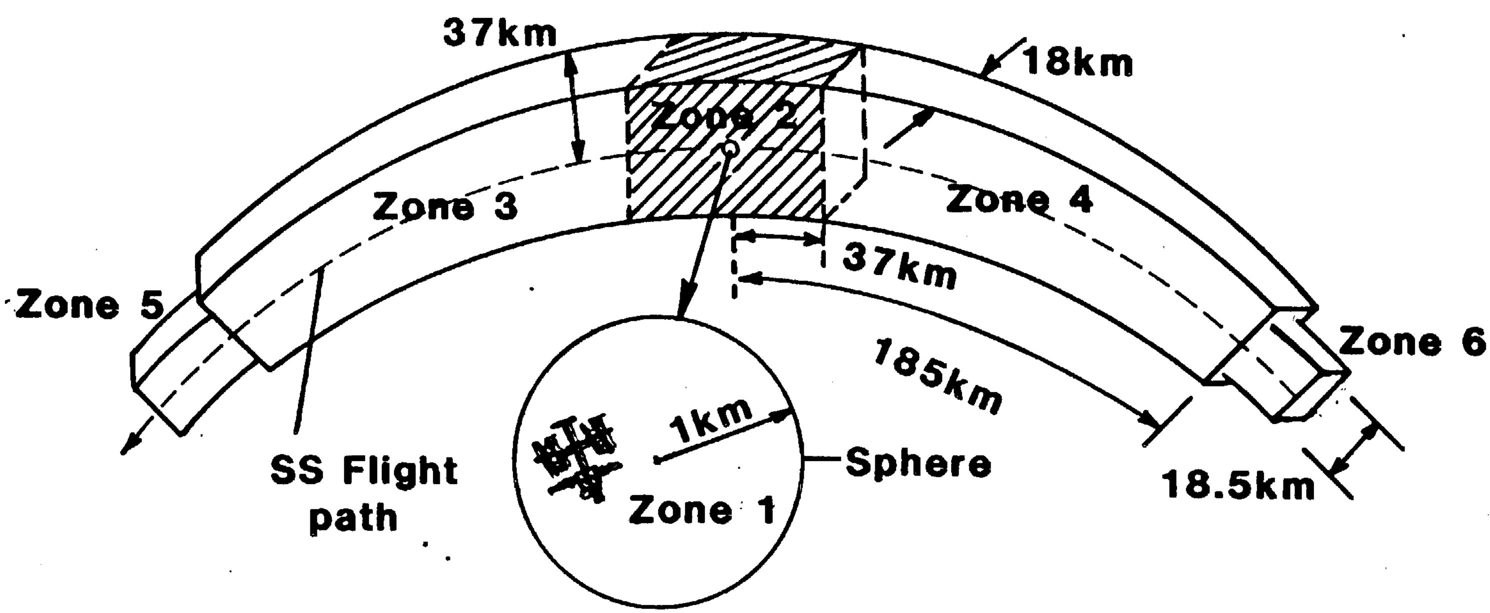
DEVELOP THE CAPABILITY TO ACCURATELY PREDICT AND EVALUATE THE RADIATION PERFORMANCE CHARACTERISTICS AND OBSCURATION EFFECTS OF COMMUNICATIONS AND TRACKING ANTENNA SYSTEMS FOR SPACE STATION PROXIMITY OPERATIONS.

JUSTIFICATION :

A MULTITUDE OF ANTENNA SYSTEMS WILL BE USED ON SPACE STATION FOR COMMUNICATIONS AND TRACKING (C/T) FUNCTIONS. PATTERN COVERAGES OF THESE ANTENNAS WILL BE AFFECTED BY STRUCTURE INTERACTION & LINE OF SIGHT PATH BLOCKAGE EFFECTS. A CAPABILITY TO PREDICT THESE EFFECTS AND PROVIDE OPTIMUM ANTENNA DESIGNS AND SITING LOCATIONS IS CRITICALLY NEEDED.

ANTENNA COVERAGE ZONES FOR IOC SPACE STATION OPERATIONS

Zone 1	PROX-OPS ZONE
Zone 2	CONTROL ZONE
Zone 3	DEPARTURE ZONE
Zone 4	RENDEZVOUS ZONE
Zone 5&6	CO-ORBIT SATELLITE ZONE



APPROXIMATE ANTENNA COVERAGE AND GAIN REQUIREMENTS FOR EACH ZONE

- SPHERICAL ANTENNA COVERAGE ($\sim$-3-0 dB GAIN) REQUIRED OUT TO 9km RADIUS
- LOWER GAIN AND SPHERICAL COVERAGE REQUIRED IN ZONE 1
- 5-8 dB ANTENNA GAIN REQUIRED OVER A $\pm 90^\circ$ CONE FORWARD AND AFT OF SS OUT TO 37km
- HIGHER DIRECTIVE GAIN REQUIRED FOR ZONES 3-6 WITHIN CONE OF ± 6- $\pm 8.5^\circ$ FORWARD AND AFT OF SS

AREAS OF STUDY

- OBSCURATIONS
  - ANTENNA PLACED ON OR IN THE VICINITY OF THE STATION OBSCURED BY PORTIONS OF THE STATION.
  - SHADOW ZONES ARE DEVELOPED IN SPHERICAL-"THETA AND PHI" REPRESENTATION.
  - SHADOW ZONES DEPEND ON SPACE STATION ORIENTATION AND THE POSITIONS OF RENDEZVOUS AND DOCKING VEHICLES IN THE VICINITY OF THE STATION.

AREAS OF STUDY (CONT'D)

- MULTIPATH EFFECTS
  - ANTENNA PLACED ANYWHERE ON THE STATION RECEIVES DIRECT AND REFLECTED ENERGY FROM CERTAIN PORTIONS OF THE STATION.
  - THE AMOUNT OF REFLECTED ENERGY DEPENDS ON THE REFLECTOR SIZE, SHAPE, ORIENTATION, AND INCIDENCE ANGLE AND POLARIZATION.
  - THE OBJECTIVE OF THE COMPUTER PROGRAM IS TO POINT OUT OBJECTS AND SURFACES THAT COULD POTENTIALLY CAUSE MULTIPATH PROBLEMS.
  - MULTIPATH EFFECTS DUE TO RENDEZVOUS AND DOCKING VEHICLES CAN ALSO BE STUDIED .

AREAS OF STUDY (CONT'D)

- **ANTENNA PATTERN COVERAGE**
  - THE PRESENCE OF SCATTERING STRUCTURES IN THE VICINITY OF AN ANTENNA RESULTS IN A MODIFIED PATTERN FOR THE ANTENNA.
  - THREE DIMENSIONAL ELECTROMAGNETIC COMPUTER CODES ARE USED TO DETERMINE THE NEAR AND FAR ZONE PATTERNS OF ANTENNAS IN THE PRESENCE OF SCATTERING STRUCTURES.
  - STRUCTUES AROUND THE ANTENNA ARE SIMULATED USING PLATES, CYLINDERS, ELLIPTIC, AND SPHERICAL SURFACES WHICH ARE OF CONDUCTING OR DIELECTRIC MATERIAL. THE PRESENCE OF VICINITY VEHICLES/OBJECTS CAN ALSO BE INCLUDED IN THE SIMULATION MODELS.
  - THE MODIFIED ANTENNA PATTERN CAN BE DEVELOPED IN THE THREE DIMENSIONAL ZONE COVERAGE. PLACEMENT OF ANTENNA CAN BE CHANGED TO STUDY STRUCTURAL EFFECTS.

METHODOLOGY / APPROACH

- RAY TRACING APPROACH
  - THE SPACE STATION CONFIGURATION IS SIMULATED USING APPROXIMATELY 20,000 POINTS EACH HAVING COORDINATE IN THE VEHICLE COORDINATE SYSTEM.
  - LINES ARE DRAWN FROM THE ANTENNA LOCATION TO EACH OF THE POINTS ON THE STATION.
  - THE SPHERICAL COORDINATE CORRESPONDING TO EACH LINE ARE STORED AND TRANSFORMED FOR PRESENTATION PURPOSES TO A SYMBOL OR LETTER.
  - THE OBSCURATION PROFILE IS OBTAINED BY CONSIDERING THE ANTENNA AS AN OMNI-DIRECTIONAL SOURCE OF LIGHT AND THE INTERCEPTED RAYS DETERMINE SHADOW ZONES.
  - SEVERAL DIFFERENT SHADOW ZONES CAN BE DISPLAYED IN DIFFERENT COORDINATE SYSTEMS.
  - GEOMETRICAL OPTICS METHODS ARE USED TO SIMULATE MULTIPATH EFFECTS. ONLY SPECULAR SINGLE BOUNCE REFLECTED ENERGY IS CONSIDERED.

SCATTERING TECHNIQUES INCORPORATED IN CODE

1. GEOMETRIC OPTICS RAY TRACING
   - For computing direct and reflected fields from plates
2. GEOMETRIC THEORY OF DIFFRACTION (GTD)
   - For computing diffracted fields from plate edges, intersecting plates and from curved surfaces (cylinders)

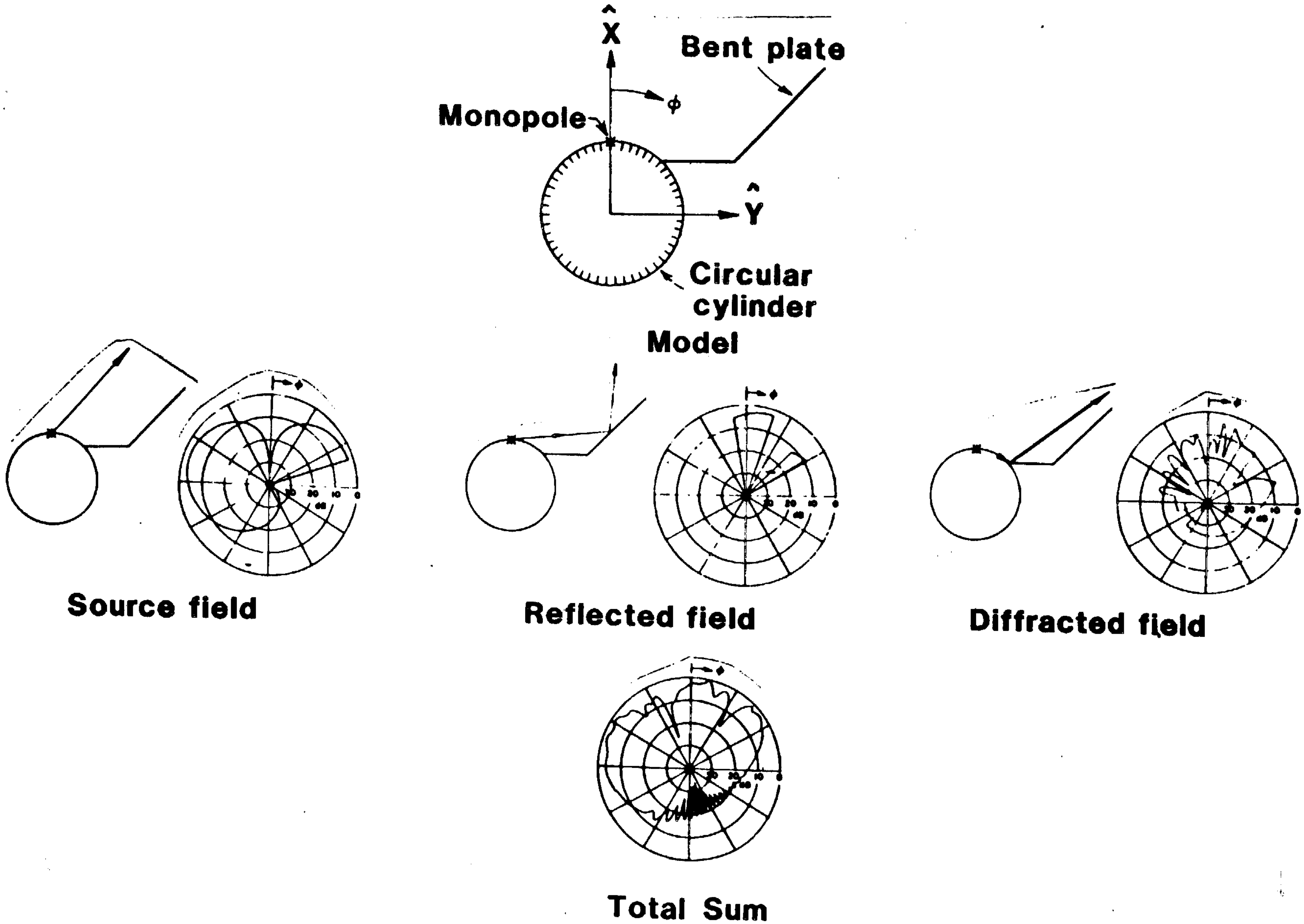
ANTENNA SOURCE TYPES WHICH CAN BE SPECIFIED IN THE CODE

1. ELECTRIC AND MAGNETIC ELEMENTS
2. UNIFORM, PIECE-WISE SINUSOIDAL OR TEO1 COSINE CURRENT DISTRIBUTION
3. ANTENNA ELEMENT DIMENSIONS (LENGTH & WIDTH)
4. MAGNITUDE AND PHASE OF EXCITATION
5. MONOPOLES, DIPOLES, SLOTS, HORNS AND ARRAYS

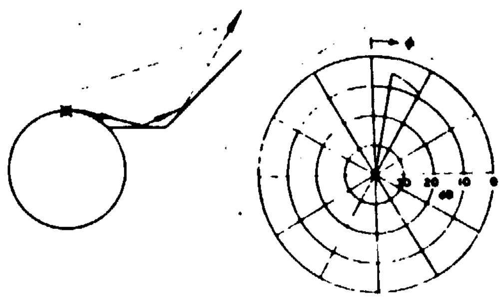
CODE LIMITATIONS

1. CODING FOR DIFF.-DIFF. FIELDS NOT COMPLETE
2. CODING FOR PLATE-CYLINDER INTERACTION FIELDS NOT COMPLETE
3. PLATES USED TO SIMULATE TRUSS STRUCTURE
   - If funds are available a tubular lattice structure simulation will be incorporated
4. LONG COMPUTER RUNNING TIME REQUIRED TO PRODUCE FULL VOLUMETRIC PATTERNS WHEN MANY PLASTES AND/OR CYLINDERS ARE SPECIFIED TO DEFINED THE STRUCTURE SUCH AS FOR THE SS

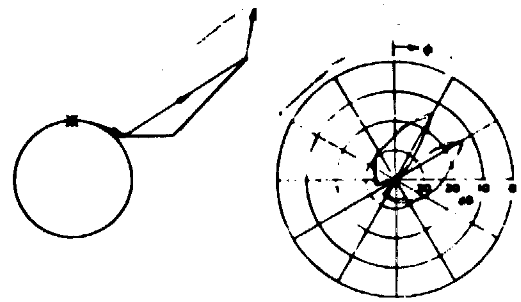
GTD TERMS AND STRUCTURAL PATTERN EFFECTS, USING BENT PLATE, CIRCULAR CYLINDER MODEL



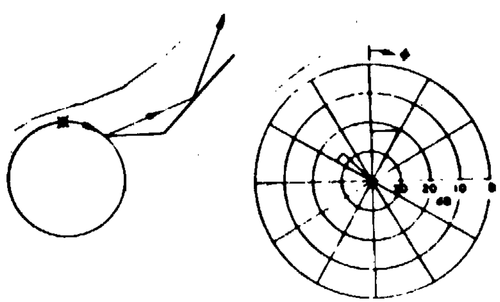
GTD TERMS AND STRUCTURAL PATTERN EFFECTS, USING BENT PLATE, CIRCULAR CYLINDER MODEL



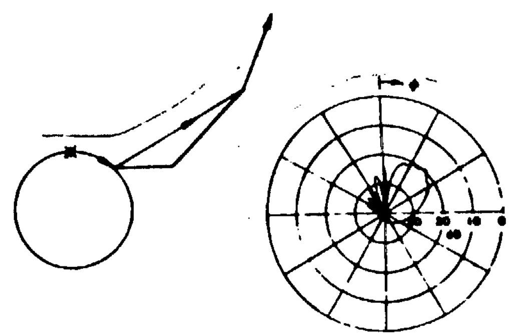
Reflected/Reflected field



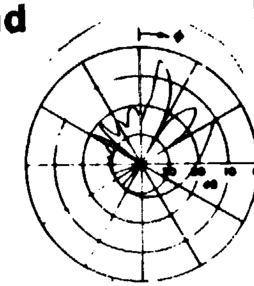
Reflected/Diffracted field



Diffracted/Reflected field

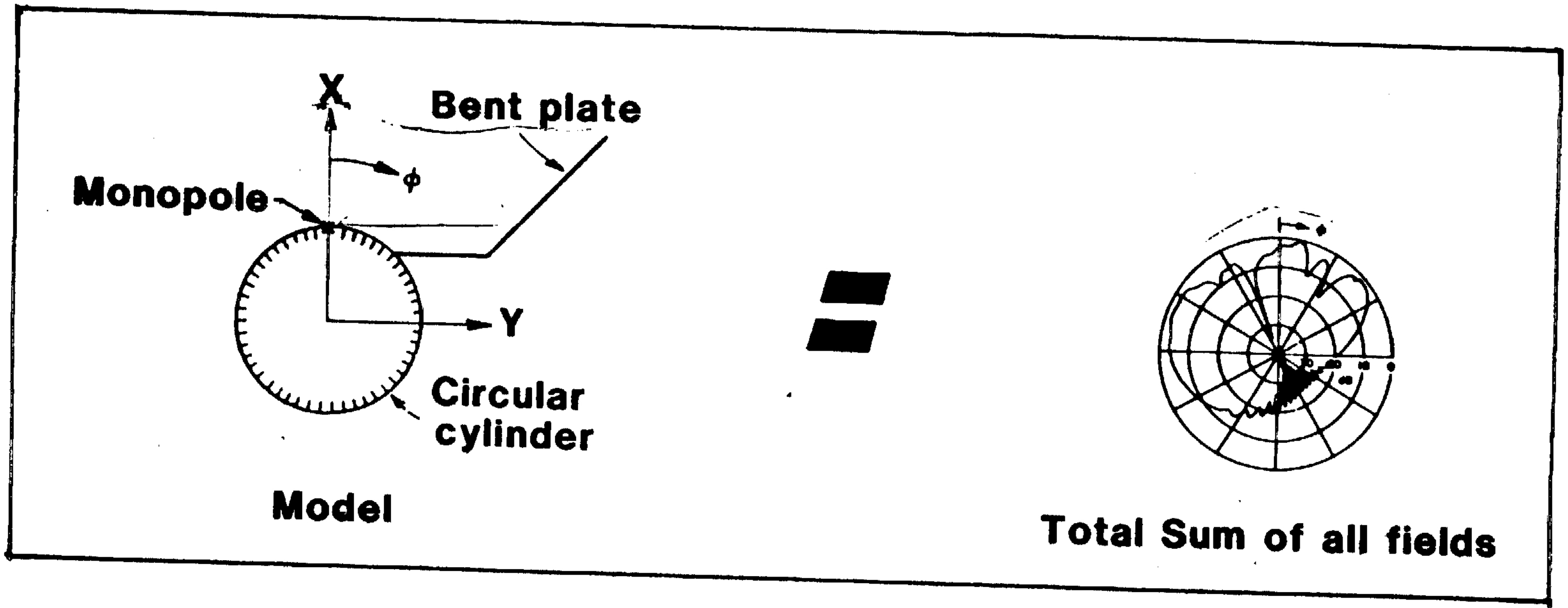


Diffracted/Diffracted field



Total Sum

GTD TERMS AND STRUCTURAL PATTERN EFFECTS, USING BENT PLATE, CIRCULAR CYLINDER MODEL

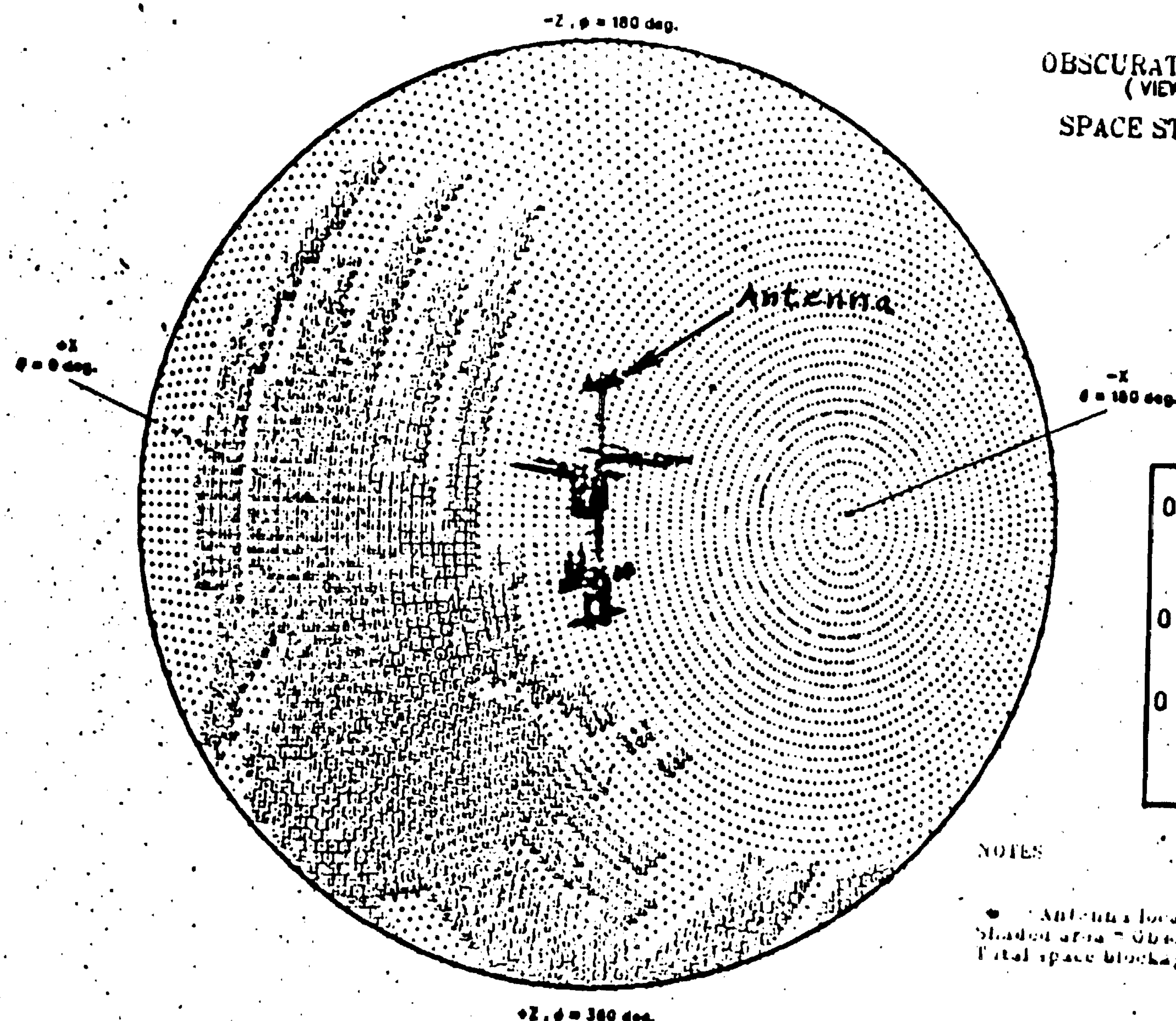


OBSCURATION

RESULTS

OBSCURATION PLOT
(VIEW 2)

SPACE STATION



- AN ISOTROPIC ANTENNA IS LOCATED NEAR THE TOP TRUSS
- OBSCURATION IS DETERMINED BY RAY TRACING
- SHADOW IS SHOWN ON AN IMAGINARY SPHERE ENCLOSING THE SS

NOTES

• Antenna location
Shaded area = Obscuration zone
Total space blockage = [illegible]

Figure 2

MULTIPATH

RESULTS

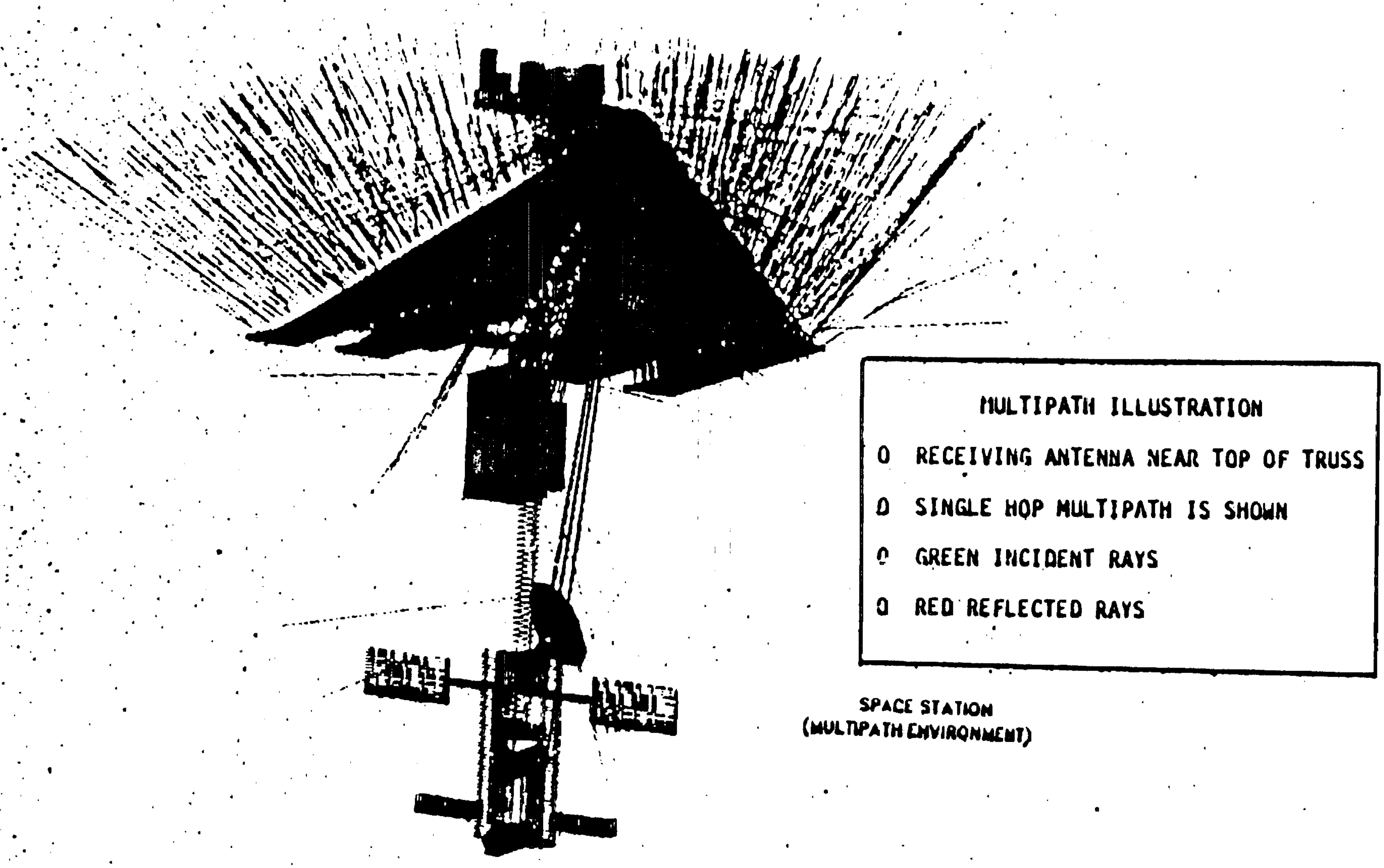
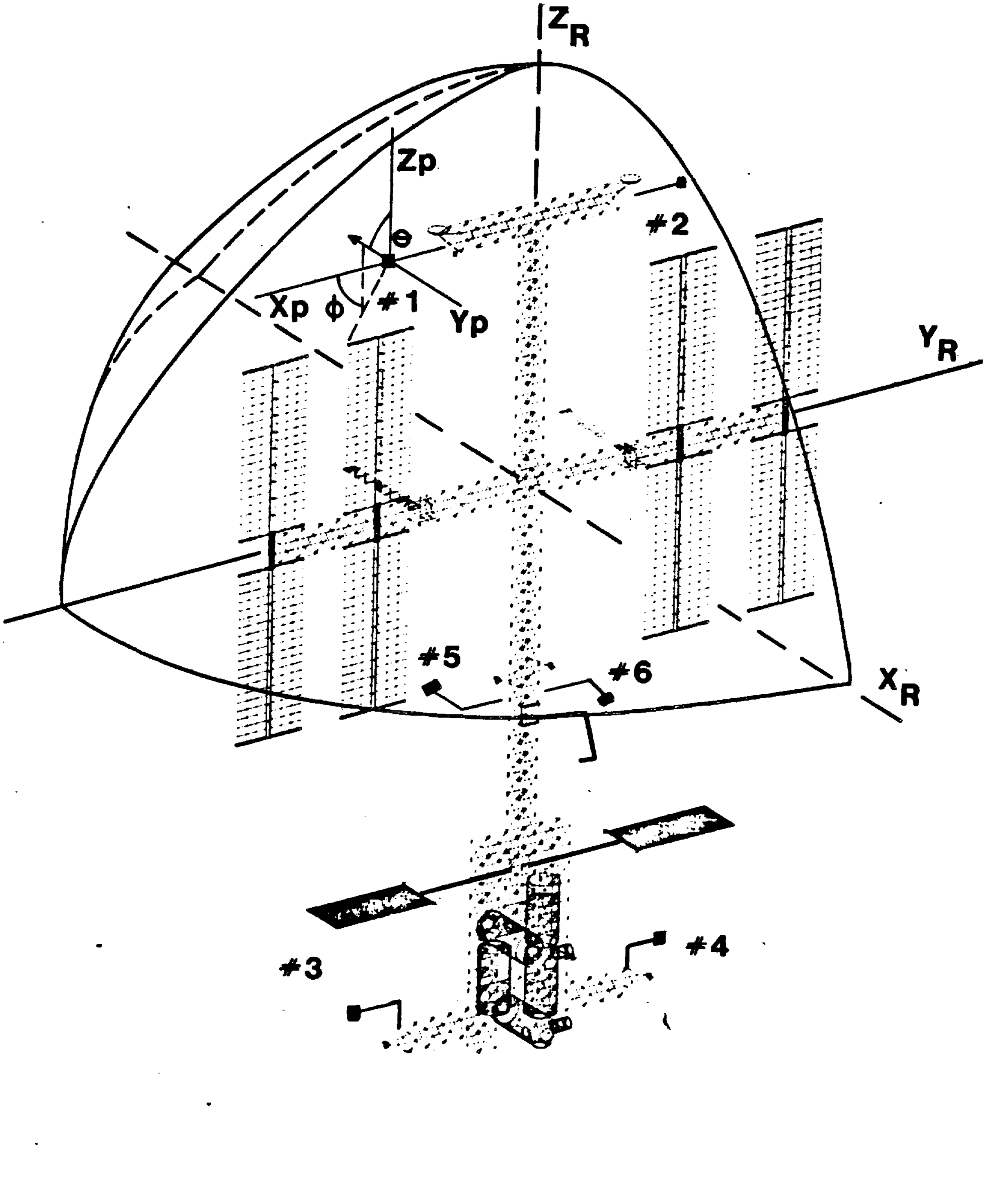
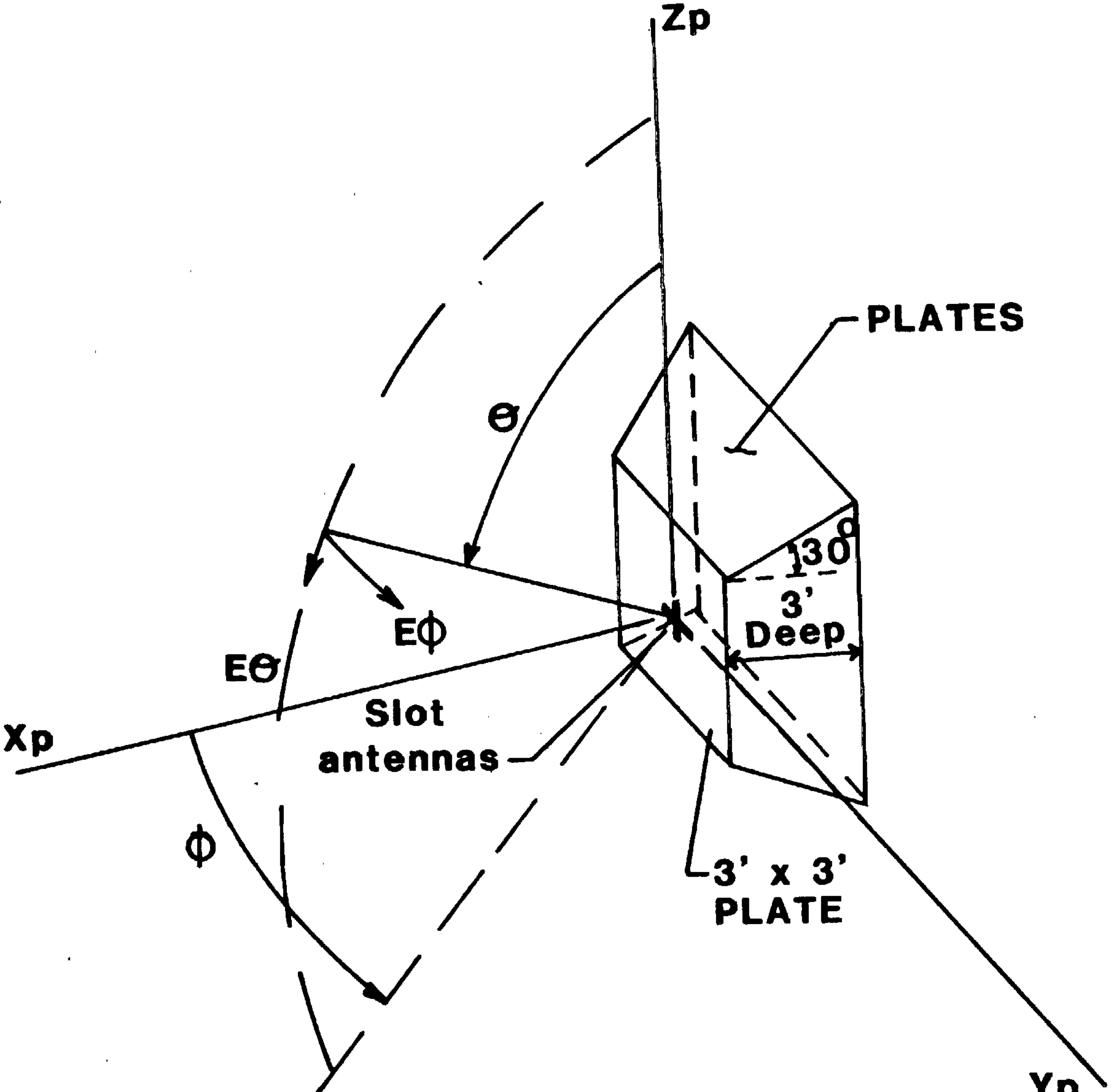

MULTIPATH ILLUSTRATION
O RECEIVING ANTENNA NEAR TOP OF TRUSS
O SINGLE HOP MULTIPATH IS SHOWN
O GREEN INCIDENT RAYS
O RED REFLECTED RAYS
SPACE STATION
(MULTIPATH ENVIRONMENT)

Figure 3

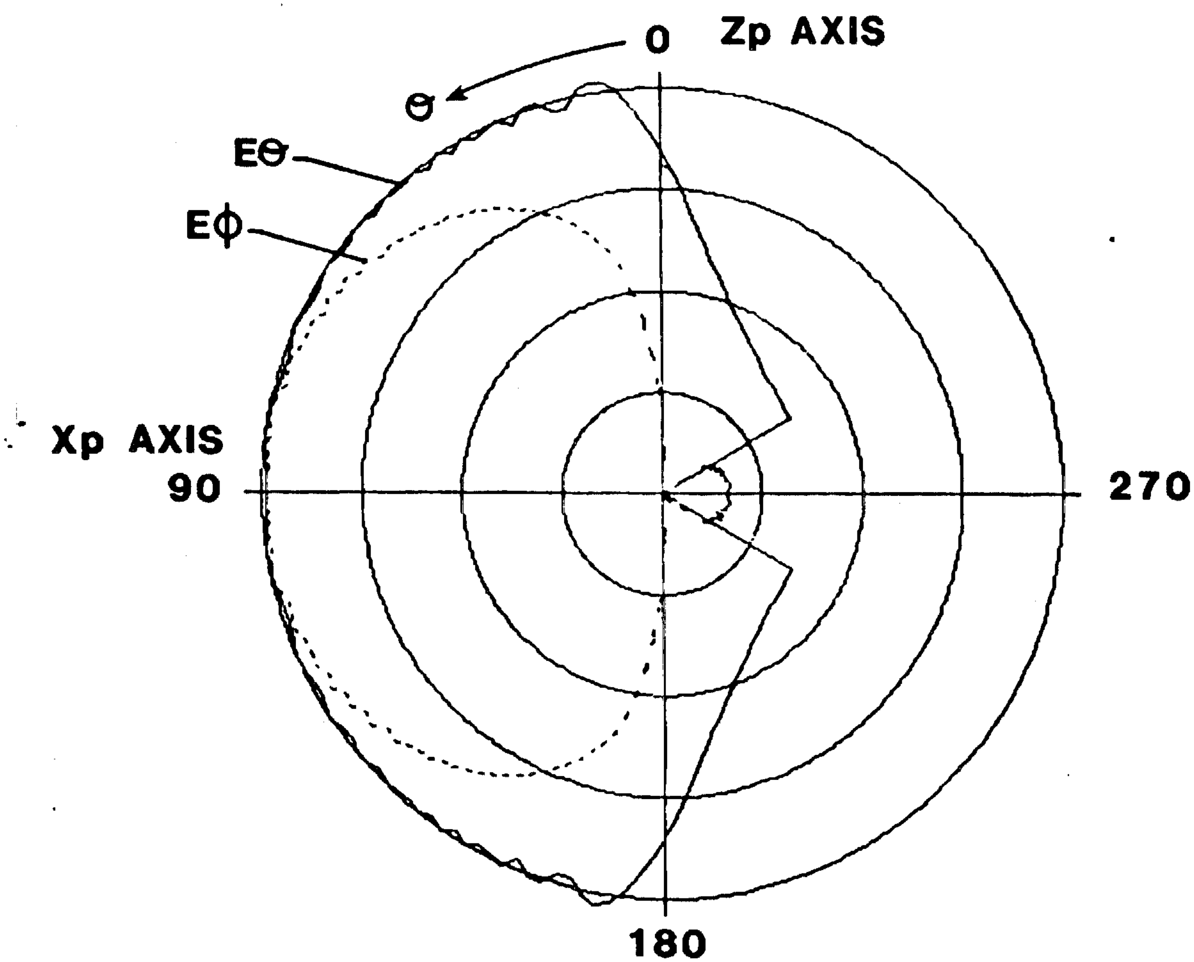
ANTENNA PATTERN COVERAGE RESULTS

PROX-OPS SPHERICAL PATTERN COVERAGE

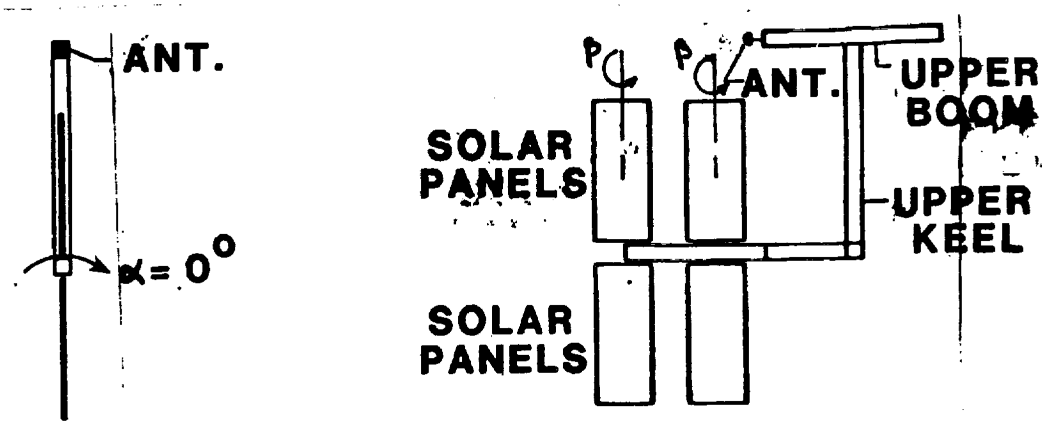




Basic antenna source used in sample pattern calculation using $\lambda/2$ vertical and horizontal thin slots, linear and circular polarizations.

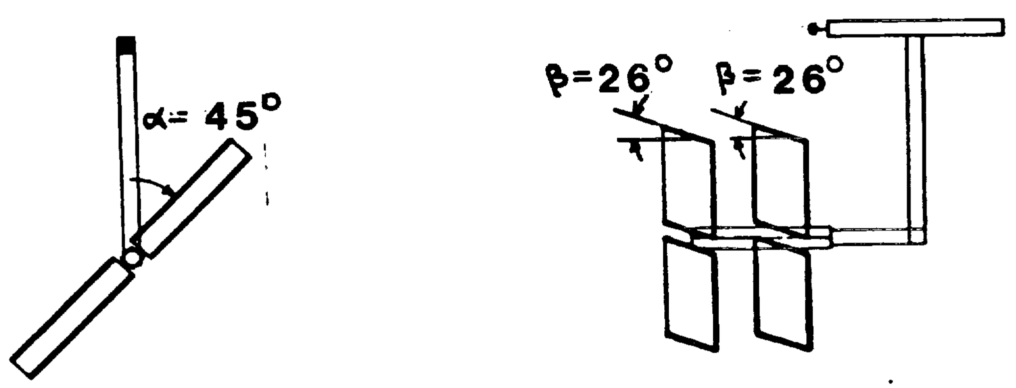


FAR FIELD PATTERN FOR ELEVATION PLANE OF $\phi = 0°$
$\lambda/2$ CROSS SLOT ANTENNA CIRCULARLY POLARIZED



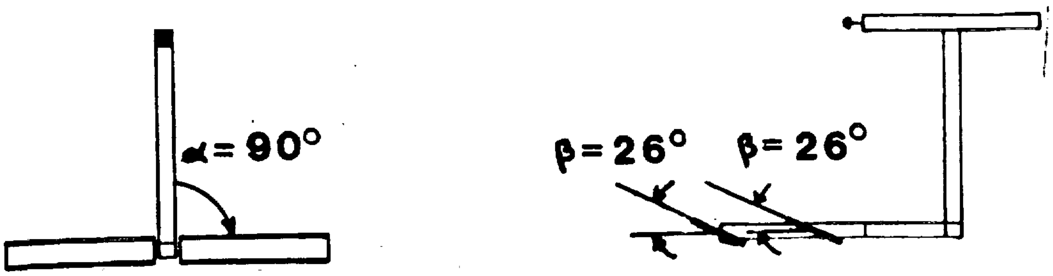
SIDE VIEW FRONT VIEW

INITIAL SOLAR PANEL POSITION (α=0,β=0)



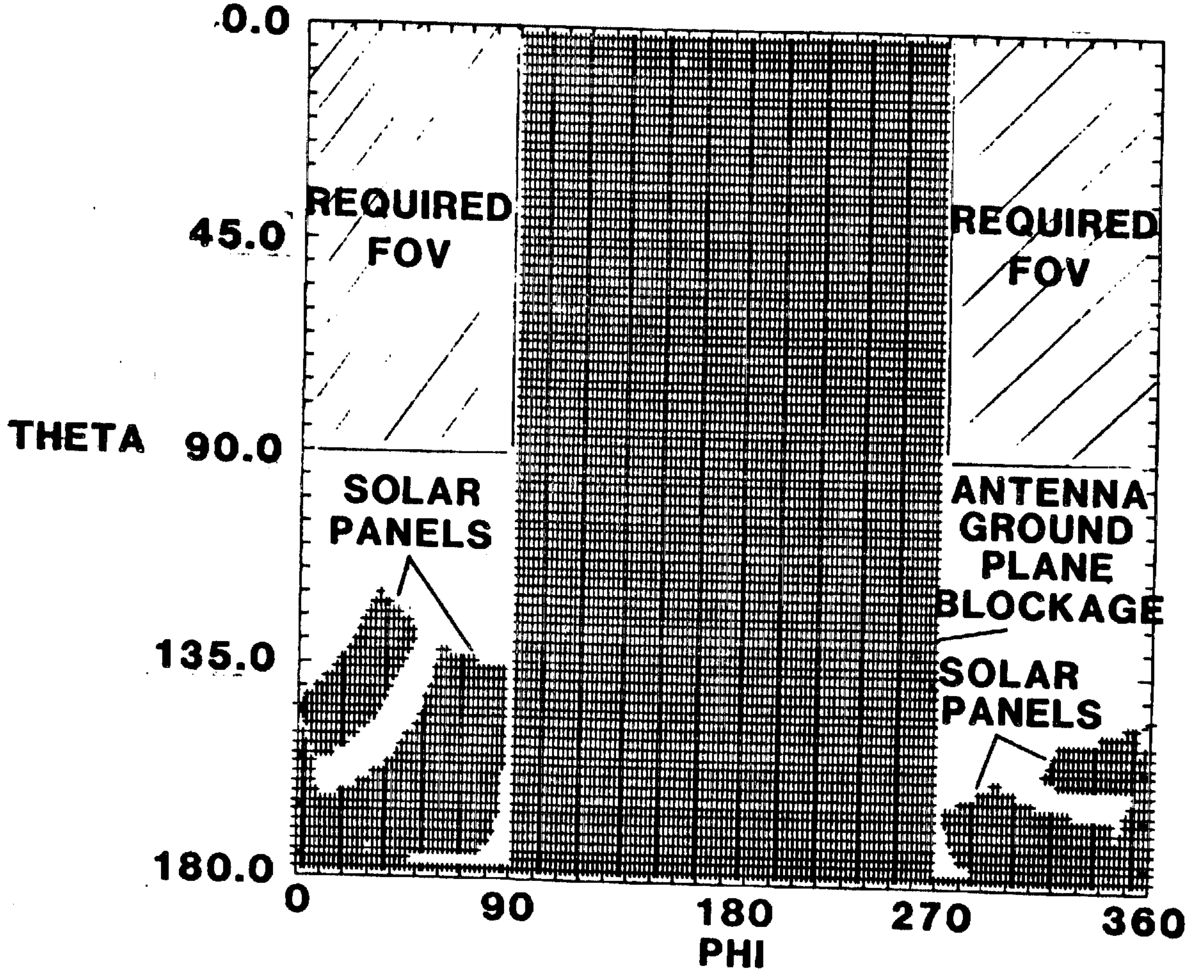
SIDE VIEW FRONT VIEW

SOLAR PANELS ROTATED 45° IN α AND 26° IN β

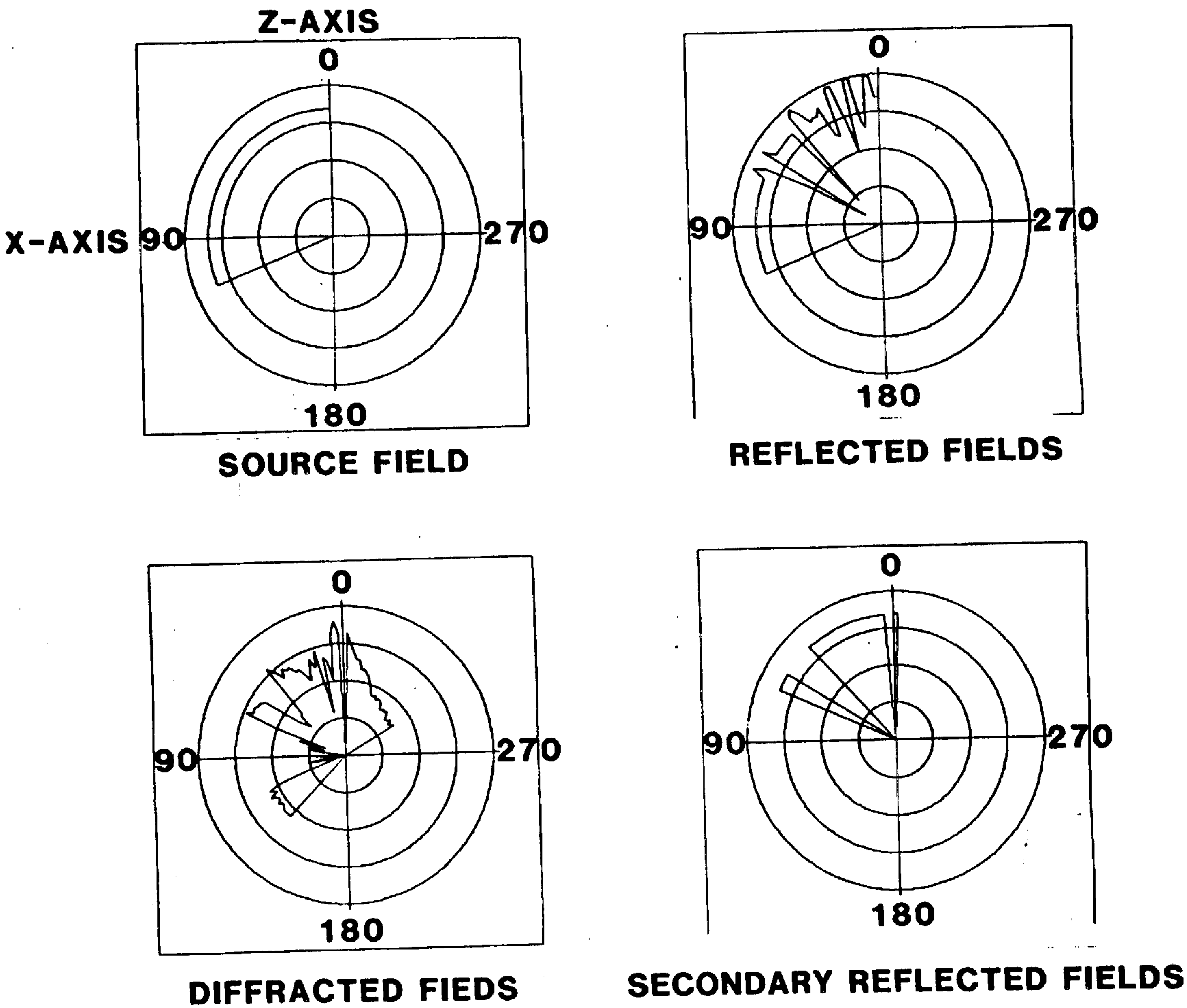


SIDE VIEW FRONT VIEW

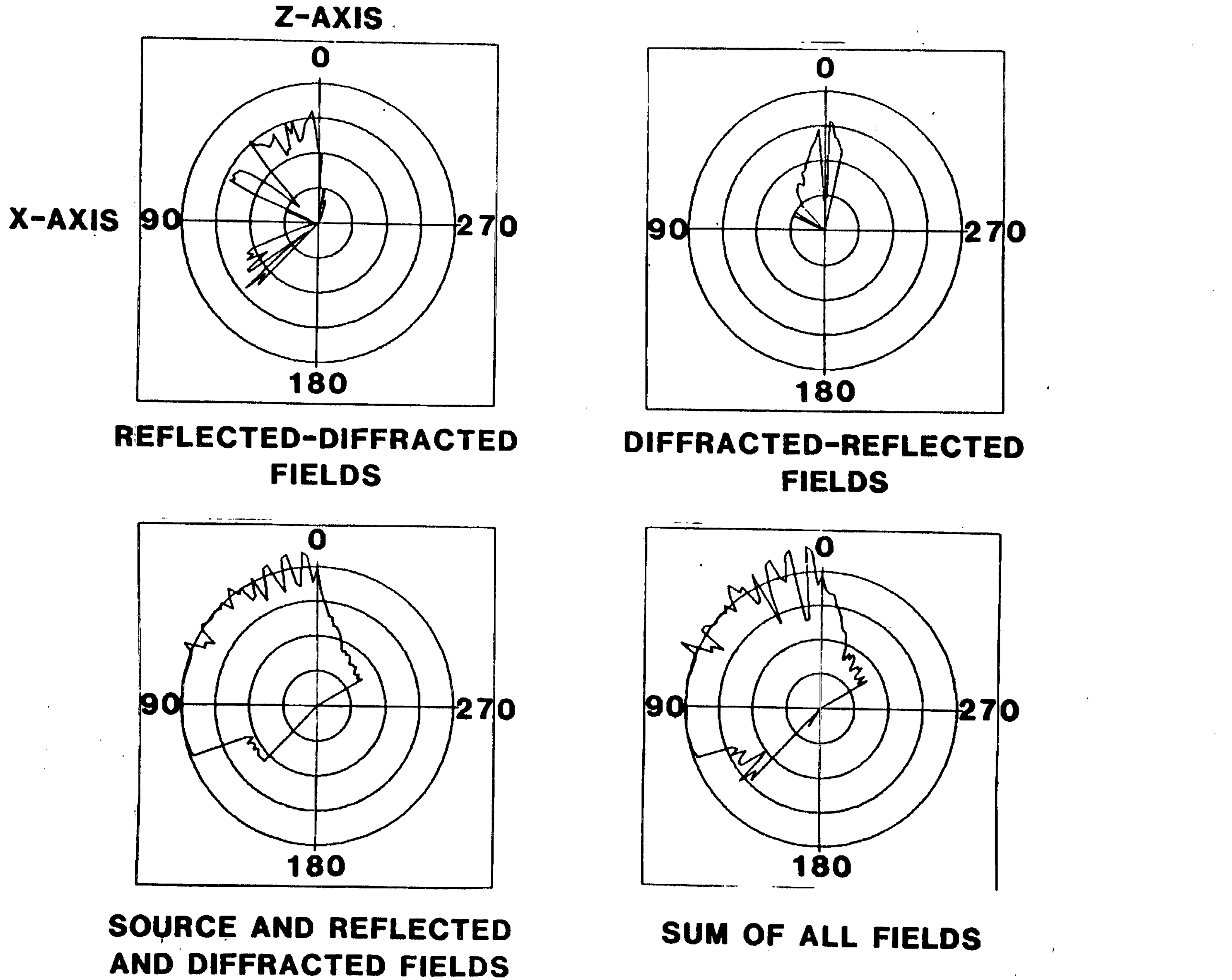
SOLAR PANELS ROTATED 90° IN α AND 26° IN β



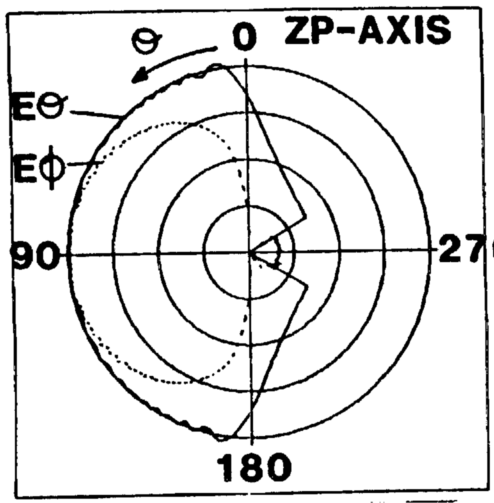
OBSCURATION PLOT FQR ANTENNA #1 WITH GROUND PLANE SOLAR PANELS ROTATED 45° IN α AND 26° IN β



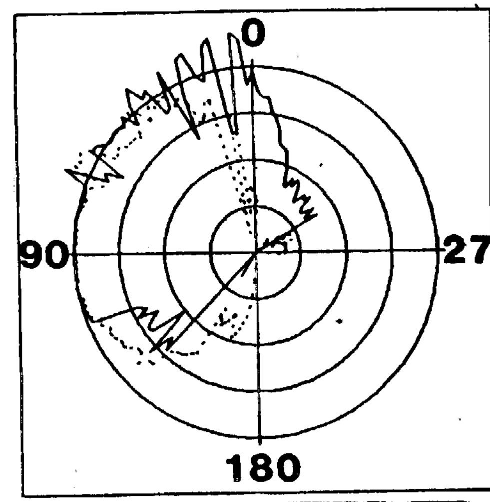
PLOTS OF THE INDIVIDUAL REFLECTED AND DIFFRACTED FIELDS.



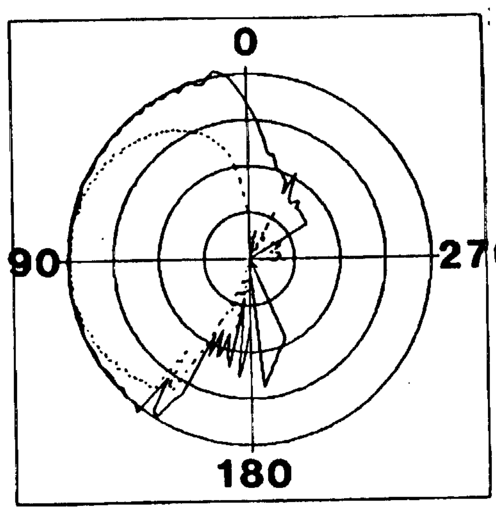
ADDITIONAL FIELD COMPONENTS AND TOTAL FAR FIELD PATTERN



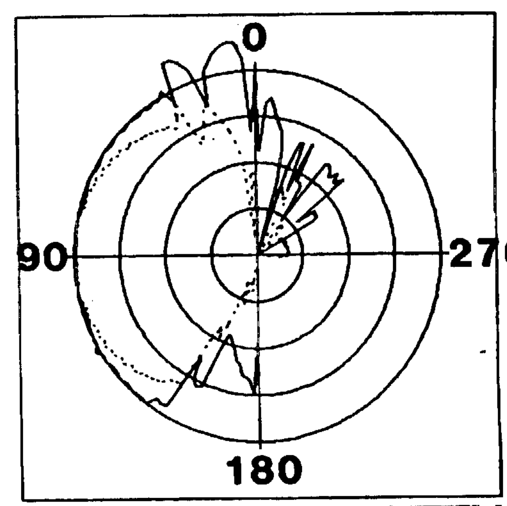
SOURCE PATTERN NO
SS STRUCTURE



WITH SOLAR PANELS IN
INITIAL POSITION $\alpha=0^\circ, \beta=0^\circ$



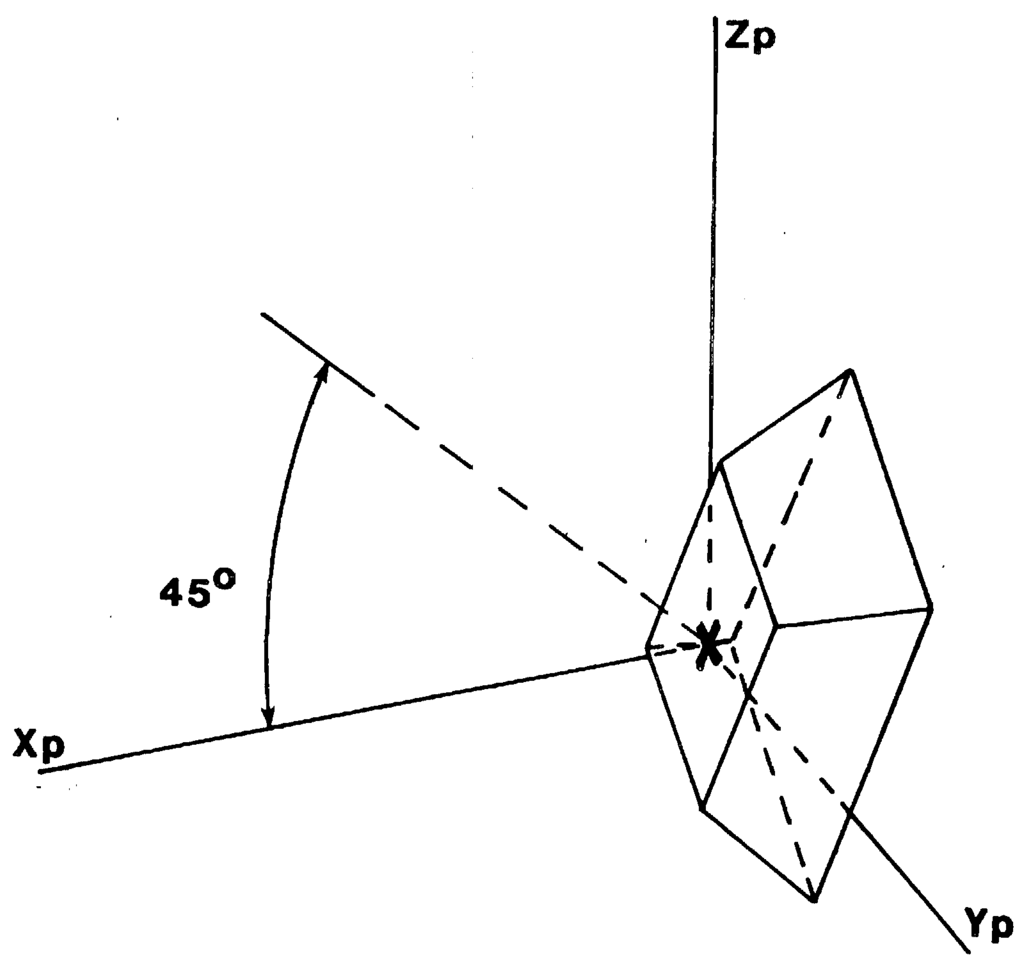
WITH SOLAR PANELS ROTATED
45° IN α AND 26° IN β

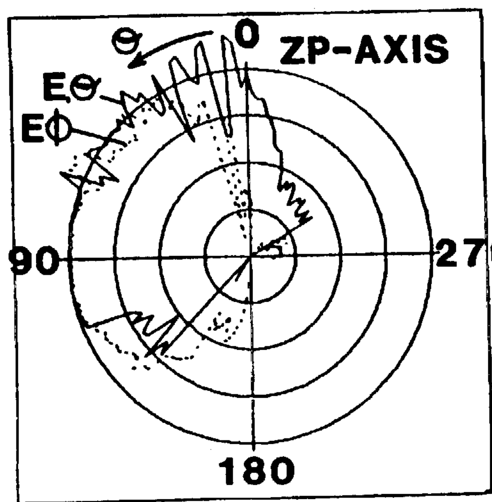


SOLAR PANELS ROTATED
90° IN α AND 26° IN β

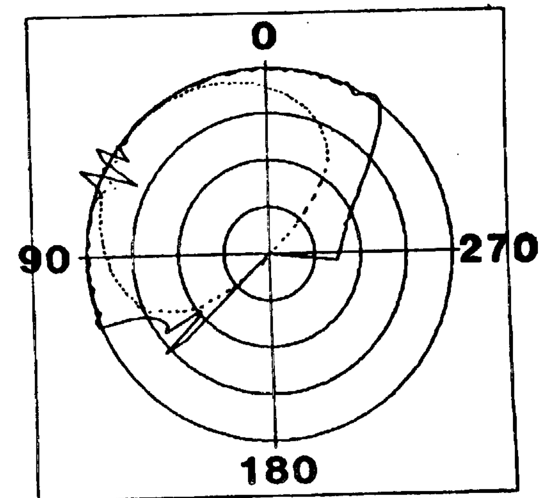
FAR FIELD PATTERNS FOR ELEVATION CUT OF $\phi=0^\circ$

BASIC ANTENNA SAME AS BEFORE EXCEPT ROTATED 45°
ABOUT THE Yp AXIS



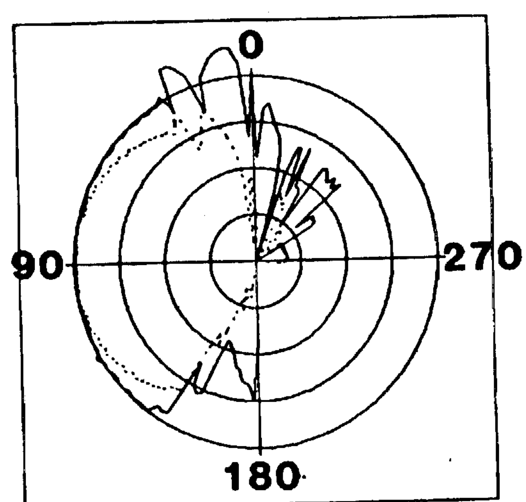


ANTENNA BORESIGHT
POINTED ALONG XP-AXIS

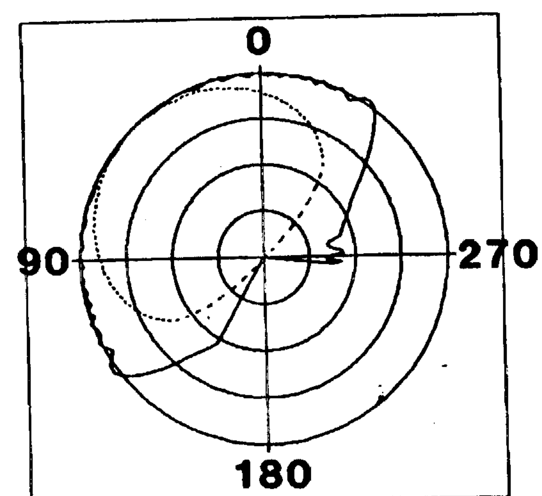


ANTENNA BORESIGHT
ROTATED -45° ABOUT YP-AXIS

SOLAR PANELS IN INITIAL POSITION $\alpha = 0° \beta = 0°$



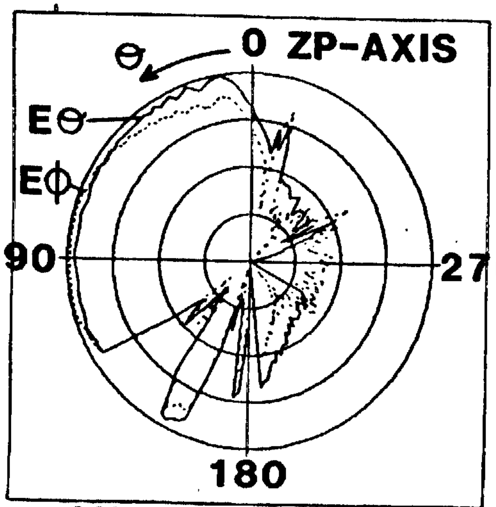
ANTENNA BORESIGHT
POINTED ALONG XP-AXIS



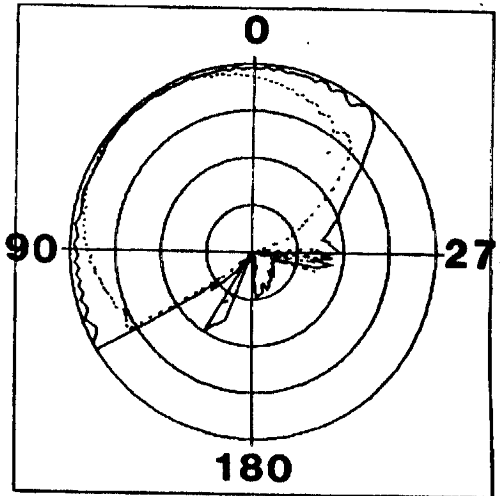
ANTENNA BORESIGHT
ROTATED -45° ABOUT YP-AXIS

SOLAR PANELS ROTATED 90° IN α AND 26° IN β

FARFIELD PATTERNS FOR ELEVATION CUT OF $\phi = 0°$

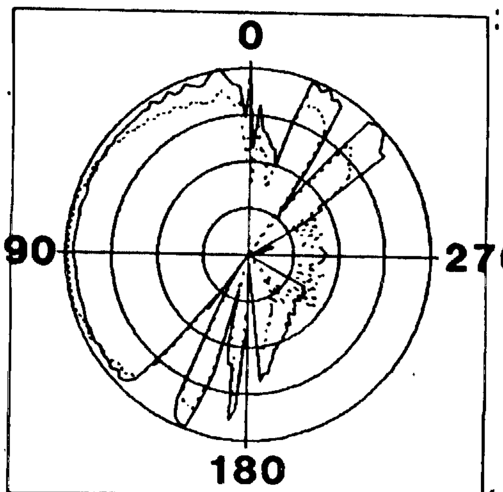


ANTENNA POINTED
ALONG XP-AXIS

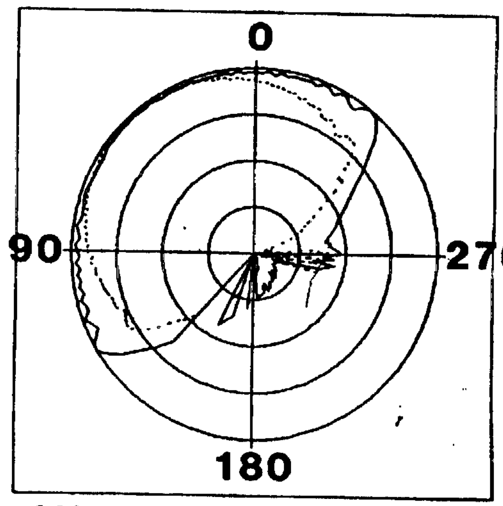


ANTENNA BORESIGHT
ROTATED -45° ABOUT YP-AXIS

SOLAR PANELS ROTATED 45° IN α AND 26° IN β



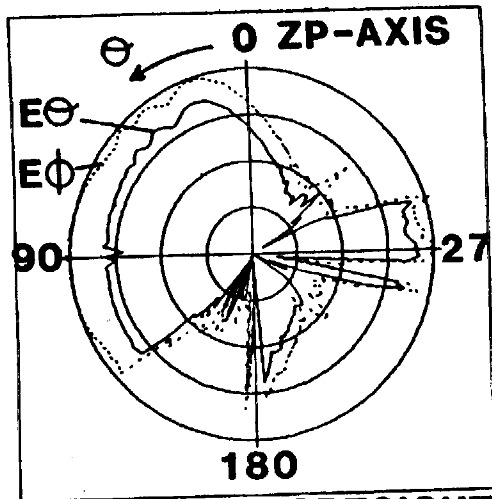
ANTENNA BORESIGHT
POINTED ALONG XP-AXIS



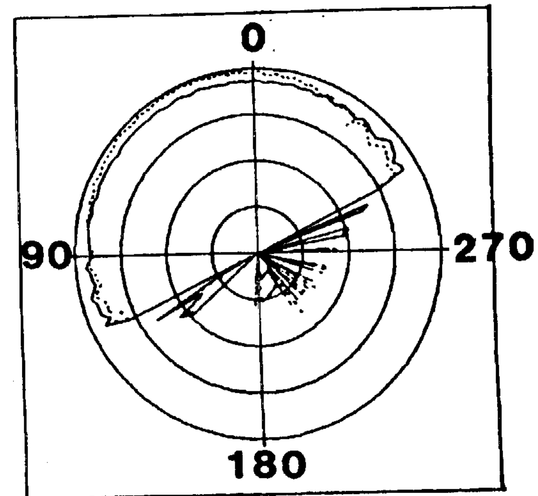
ANTENNA BORESIGHT
ROTATED -45° ABOUT YP-AXIS

SOLAR PANELS ROTATED 90° IN α AND 26° IN β

FAR FIELD PATTERNS FOR ELEVATION CUT OF $\phi = 30°$

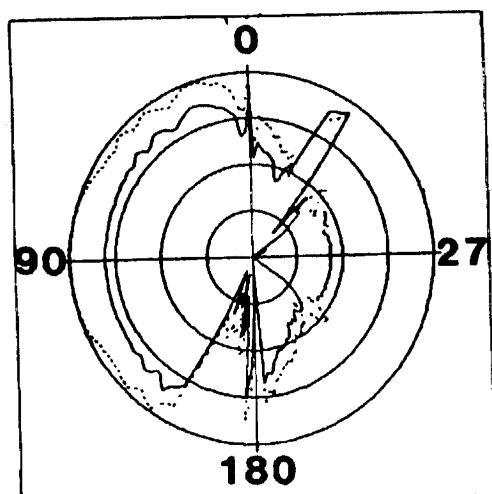


ANTENNA BORESIGHT
POINTED ALONG XP-AXIS

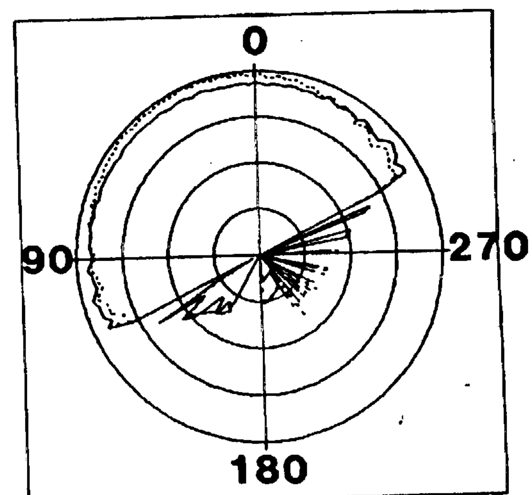


ANTENNA BORESIGHT
ROTATED-45° ABOUT YP-AXIS

SOLAR PANELS ROTATED 45° IN α AND 21° IN β



ANTENNA BORESIGHT
POINTED ALONG XP-AXIS



ANTENNA BORESIGHT
ROTATED-45° ABOUT YP-AXIS

SOLAR PANELS ROTATED 90° IN α AND 26° IN β

FAR FIELD PATTERNS FOR ELEVATION CUT OF $\phi = 60°$

CONCLUSIONS AND RECOMMENDATIONS

- CODES HAVE BEEN DEVELOPED WHICH CAN COMPUTE OBSCURATION FOR ANTENNAS MOUNTED ON THE SS
- PRELIMINARY CODES HAVE BEEN DEVELOPED FOR COMPUTING SIMPLE MULTIPATH EFFECTS
- A PRELIMINARY PATTERN PREDICTION CODE HAS BEEN DEVELOPED WHICH CAN PROVIDE LIMITED ANTENNA PATTERN COMPUTATIONS
- IMPROVED VERSION OF PATTERN CODE NEEDED
  - To provide rapid full volume pattern calculations
  - To incorporate tubular structure

SESSION 4

SPACE TRAFFIC CONTROL

FORMATION FLYING TECHNIQUES

BY: DAVID M. HENDERSON
TRW DEFENSE SYSTEM GROUP
HOUSTON, TEXAS

FEBRUARY 20, 1985

SCOPE AND DEFINITIONS APPLIED TO FORMATION FLYING

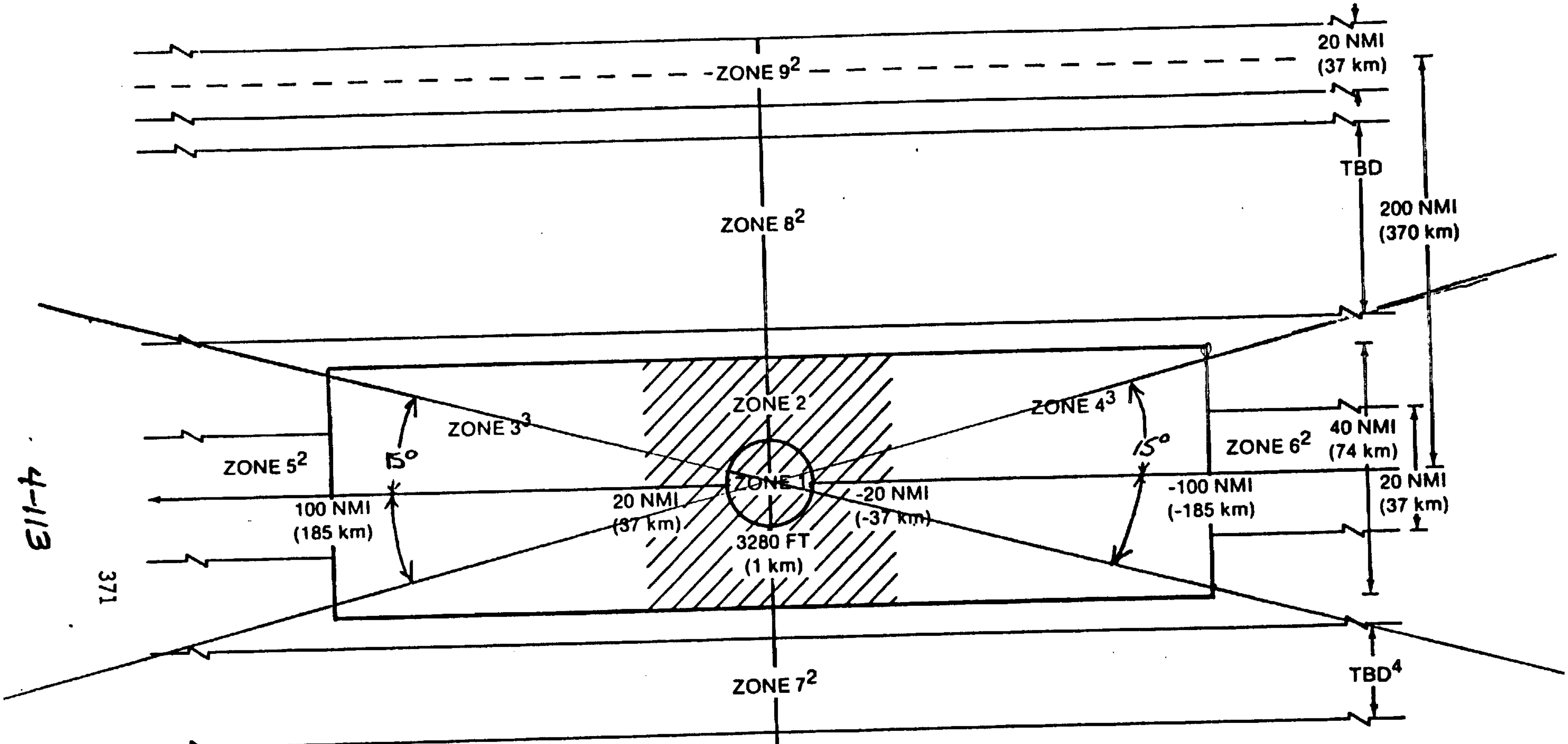
A. CONTROL ZONE CONCEPTS

- CONTROL ZONE CONCEPTS ARE BEING DEVELOPED*
- USE OF CONTROL ZONES MAY BE ANALOGOUS TO FAA/ATC PROCEDURES
- ZONES 5 AND 6, 100NM FORWARD AND AFT OF THE SPACE STATION, ARE RECOMMENDED FOR THE FORMATION FLYERS
- A 15° CONE LIMIT IS BEING PROPOSED FOR ON-BOARD TRACKING AND LOS REQUIREMENTS**

* "SPACE STATION REFERENCE CONFIGURATION DESCRIPTION", JSC-19989, AUGUST 1984.

** SAME AS ABOVE, SECTION 4.4.2.

TRW DEFENSE SYSTEMS GROUP



ZONE ASSIGNMENTS:
1. PROXIMITY OPERATIONS ZONE
2. CONTROL ZONE
3. DEPARTURE ACTIVITY ZONE
4. RENDEZVOUS ACTIVITY ZONE
5. LEADING COORBITING SATELLITE ZONE
6. TRAILING COORBITING SATELLITE ZONE
7. LOWER NON-COORBITING SATELLITE ZONE
8. UPPER NON-COORBITING SATELLITE ZONE
9. PARKING ORBIT ZONE

NOTES:
1. THIS DRAWING IS CURVILLINEAR AND IS NOT DRAWN TO SCALE.
2. THIS ZONE IS CONTINUOUS ABOUT THE EARTH
3. THIS ZONE BEGINS AT THE SPACE STATION
4. THE MINIMUM OPERATING ALTITUDE FOR THIS ZONE IS ~ **100 NMI (~185 km)**
5. ZONES 2,3,4,5, & 6 EXTEND ~ ±9 km(±5 NMI) OUT-OF-PLANE
6. ZONES 7,8 AND 9 ARE SPHERICAL SHELLS CENTERED ABOUT THE EARTH

Figure 4.3.8.2.1-1 - OPERATIONAL CONTROL ZONES.[1]

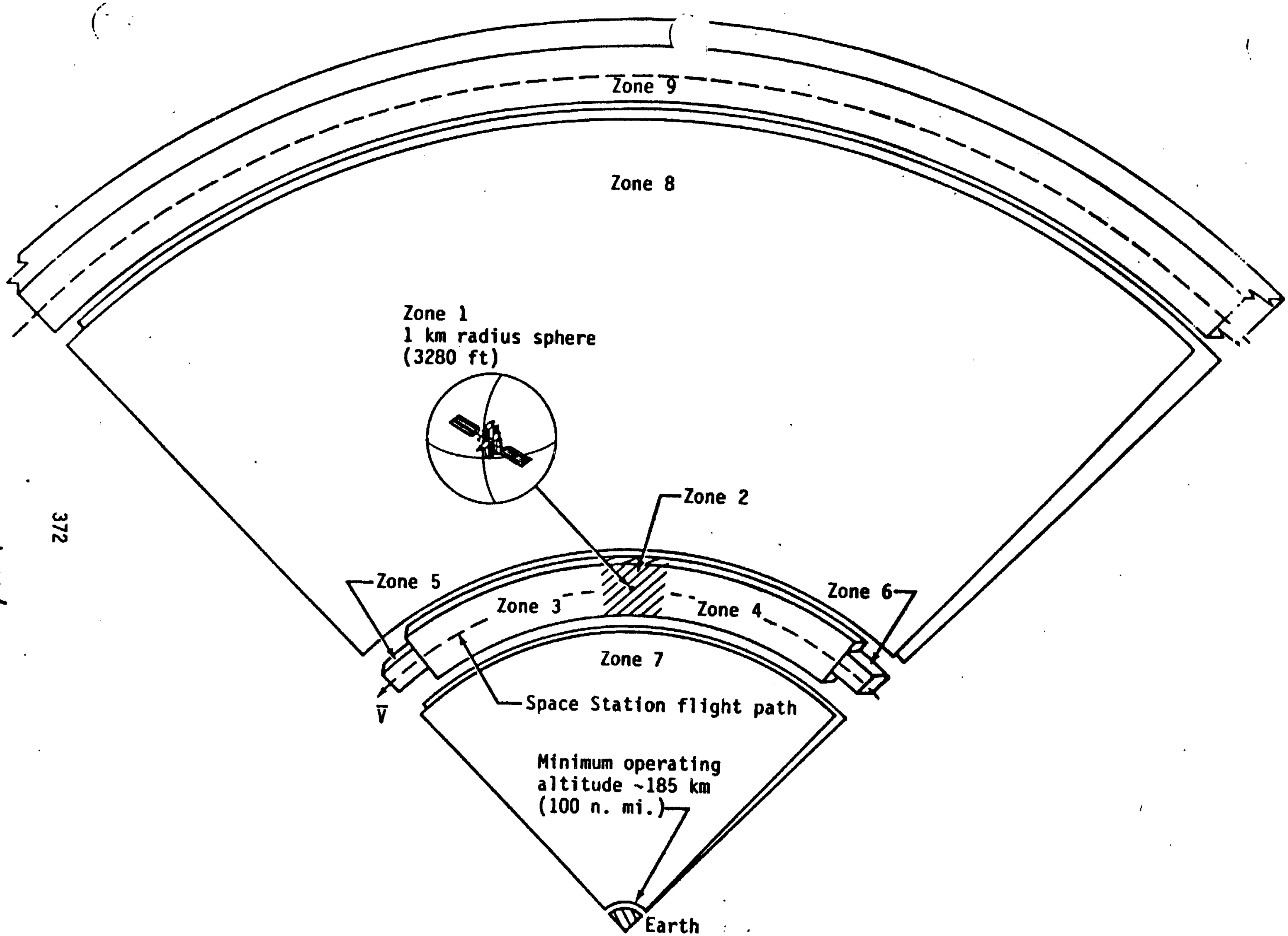


Figure 4.3.8.2.1-2 - SCALE DRAWING OF OPERATIONAL CONTROL ZONES IN 3 DIMENSIONS

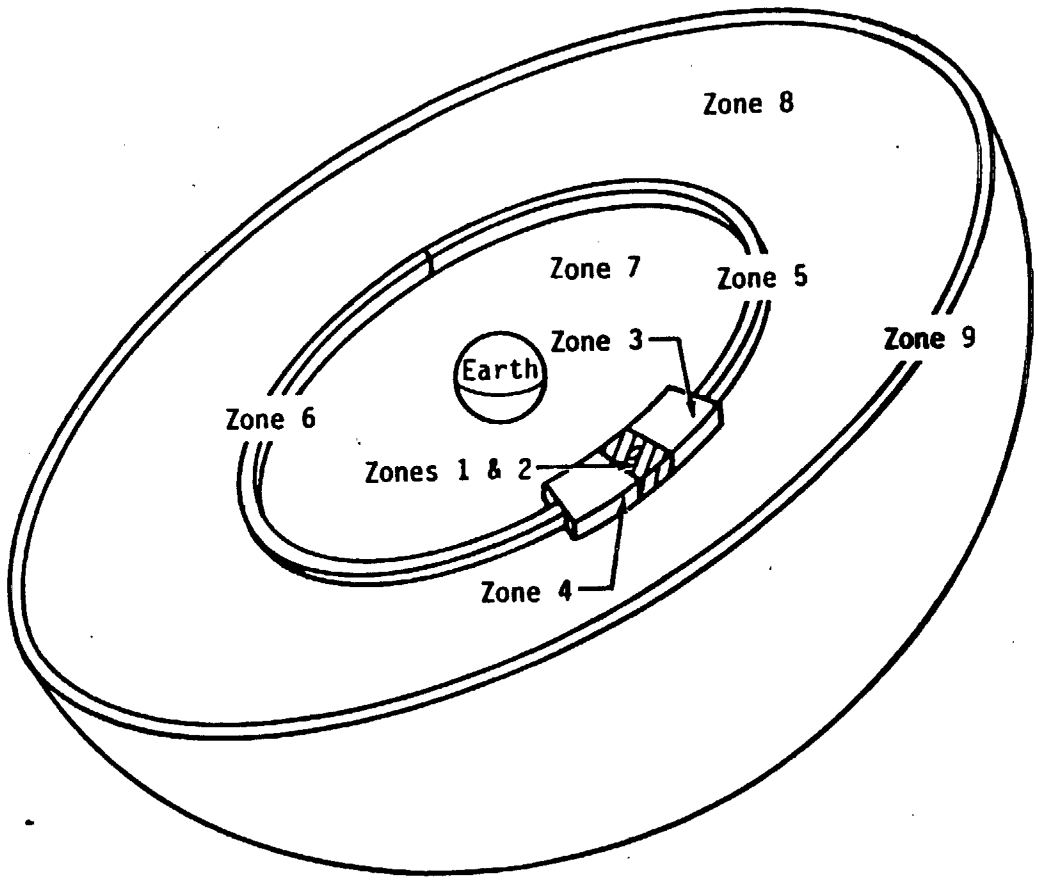


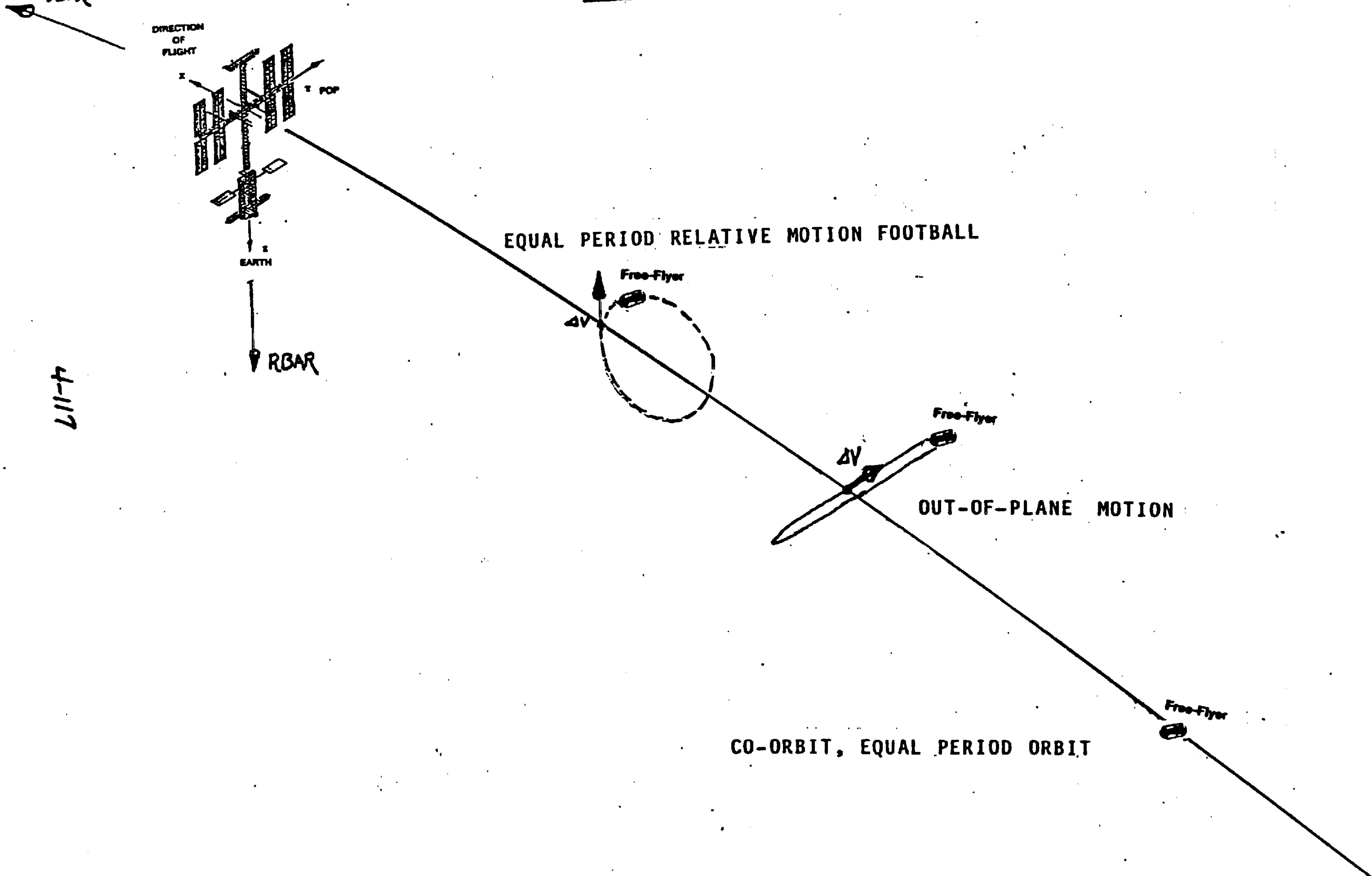
Figure 4.3.8.2.1-3 - CUTAWAY VIEW OF OPERATIONAL CONTROL ZONES (HEMISPHERICAL CUTAWAY)

B. ORBIT STRATEGIES

- ONLY CO-ORBIT, EQUAL PERIOD ORBITS ARE CONSIDERED.
- FORMATION FLYERS ARE PLACED FORE AND AFT NEAR THE VBAR LINE.
- SOME SMALL OUT-OF-PLANE MOTION IS CONSIDERED TO ENHANCE SEPARATION REQUIREMENTS WHEN THE DENSITY OF THE FORMATION FLYERS IS INCREASED.
- FOR MINIMUM DEPLOYMENT AND RETRIEVAL ENERGY REQUIREMENTS, THE RELATIVE MOTION FOOTBALL IS A BASIC ORBIT PATTERN FOR THE FORMATION.

TRW DEFENSE SYSTEMS GROUP

ORBIT STRATEGIES



C. ONLY FIRST LEVEL OF SAFETY ADDRESSED IN THIS STUDY OF FORMATION FLYING TECHNIQUES

- BASICALLY THREE LEVELS OF COLLISION SAFETY EXIST IN THE SPACE TRAFFIC CONTROL ENVIRONMENT.

  (1) SAFETY FROM COLLISIONS BETWEEN KNOWN PARTICIPATING VEHICLES

  - SPACE STATION
  - SPACE SHUTTLE
  - SPACE TRANSFER VEHICLES
  - FORMATION FLYERS

  (2) SAFETY FROM COLLISION BETWEEN NON-PARTICIPATING VEHICLES IN KNOWN ORBITS

  - THE NORAD CATALOGED SPACE OBJECTS

  (3) SAFETY FROM COLLISION WITH NON-PARTICIPATING SPACE OBJECTS IN UNKNOWN ORBITS

  - SPACE DEBRIS

- SAFETY LEVELS (2) AND (3) ABOVE MUST ALSO BE A PART OF THE INTEGRATED TRAFFIC CONTROL PROCEDURES.

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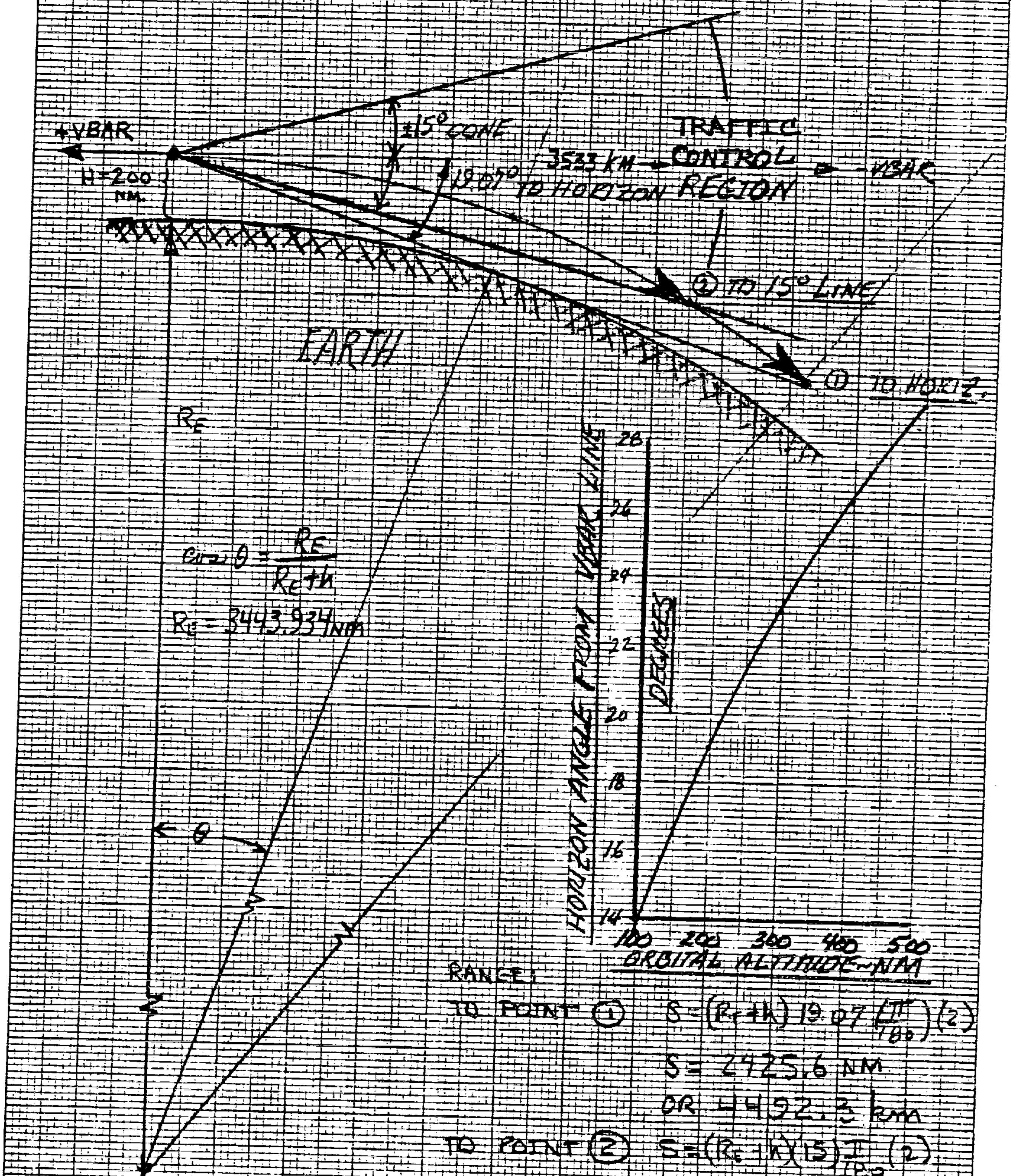
ORBITAL REQUIREMENTS FOR FORMATION FLYING

A. ON-ORBIT GEOMETRY

- PLACEMENT WITHIN 15° TRACKING CONE STILL REQUIRES HORIZON LIMITS AND LIGHTING CONSTRAINTS DUE TO SUN, MOON, BRIGHT PLANETS AND BRIGHT STARS.
- EARTH HORIZON IS 22° DOWN FROM HORIZONTAL AT 275NM ORBITAL ALTITUDE.
- A 10NM VERTICAL DISPLACEMENT AT 100NM GIVES A 5.7° DEGREE TRACKING ARC.
- TRACKING ARCS BECOME SMALL AS THE DISTANCE TO THE FORMATION FLYERS IS INCREASED, HENCE LARGER DIAMETER FORMATIONS WILL BE REQUIRED AS THE RANGE IS INCREASED FOR THE SAME TRACKING RESOLUTION.

TRW DEFENSE SYSTEMS GROUP

ON-ORBIT GEOMETRY



RANGE:

TO POINT ① $S=(R_E+h)\,19.07\left(\frac{\pi}{180}\right)(2)$

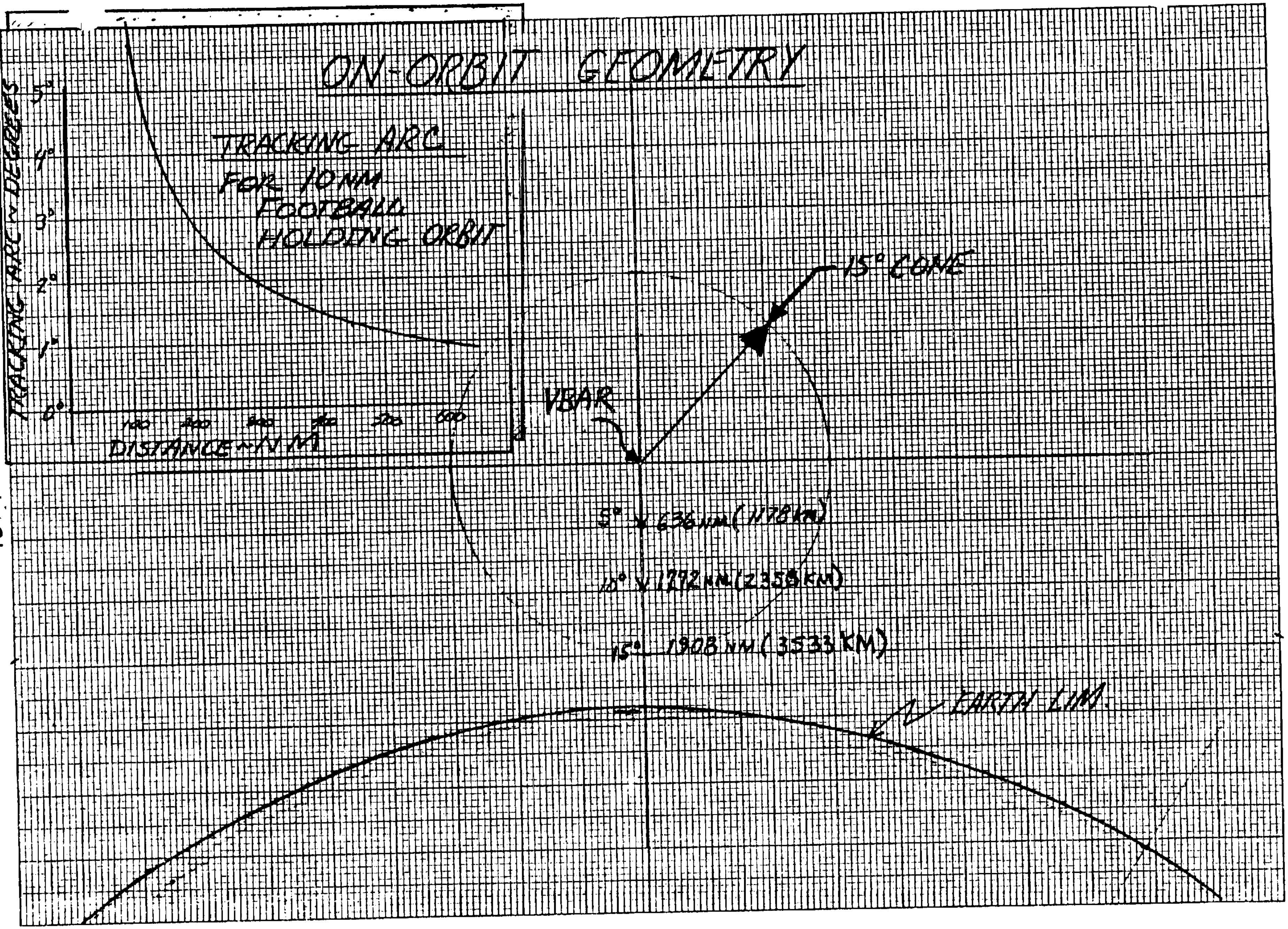
$S = 2425.6$ NM

OR 4492.3 km

TO POINT ② $S=(R_E+h)(15)\frac{\pi}{180}(2)$

$S=1907.96$ NM

OR 3533.54 km

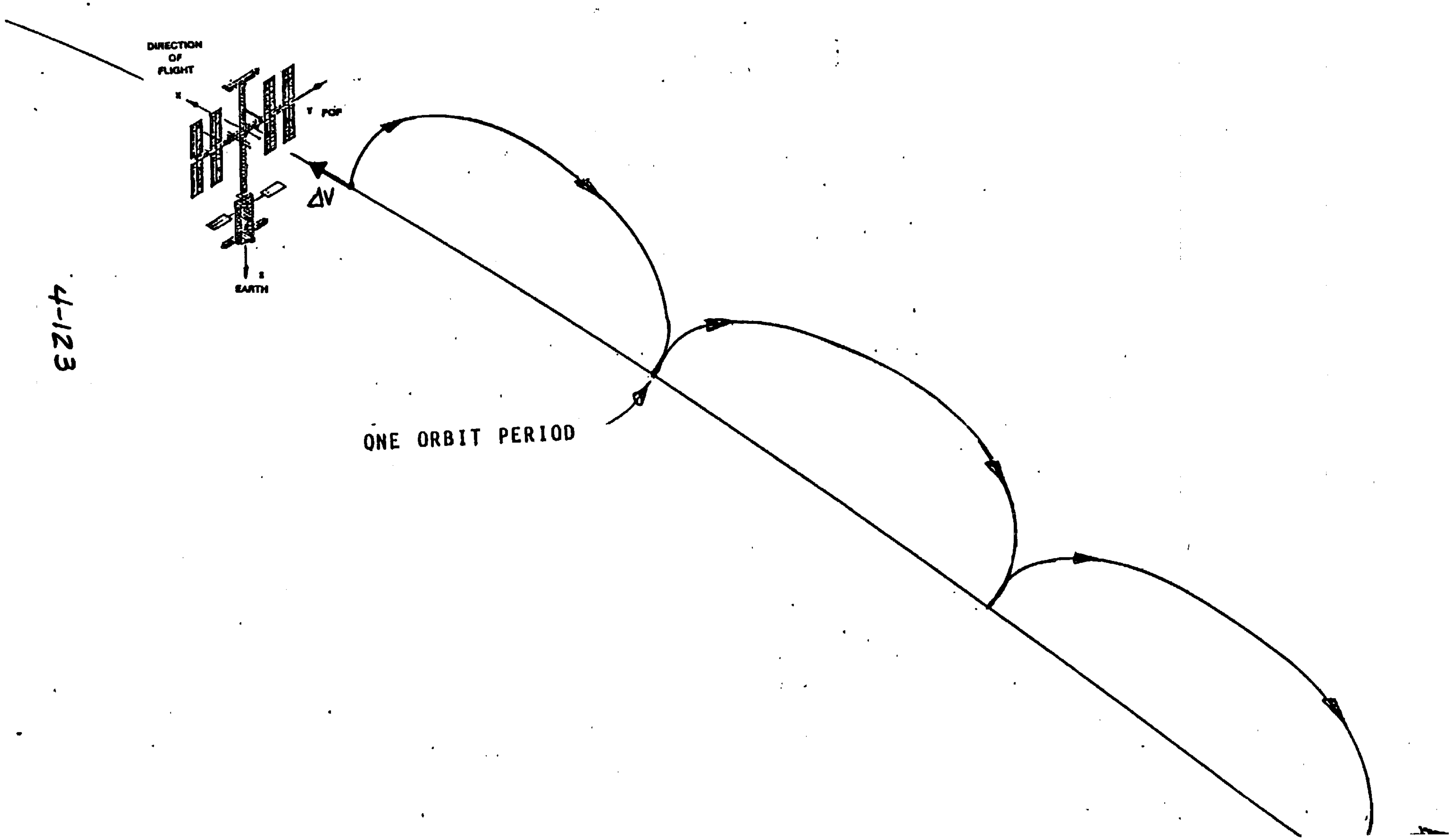

ON-ORBIT GEOMETRY
TRACKING ARC
FOR 10NM
FOOTBALL
HOLDING ORBIT
TRACKING ARC ~ DEGREES
5°
4°
3°
2°
1°
0°
100 200 300 400 500 600
DISTANCE ~ NM
15° CONE
VBAR
5° 636 NM (1178 KM)
10° 1272 NM (2355 KM)
15° 1908 NM (3533 KM)
EARTH LIM.

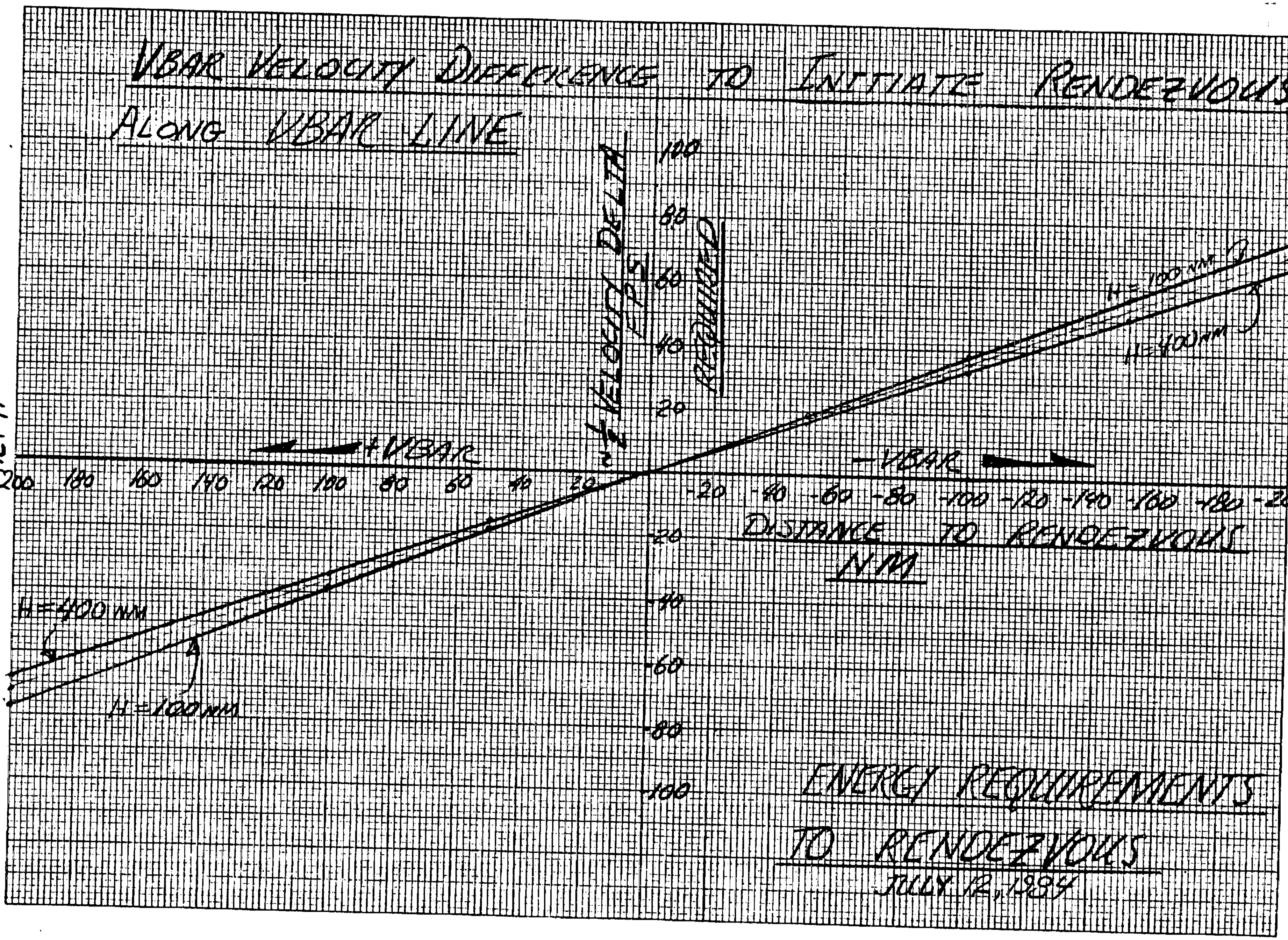
B. VBAR DELTA V RELATIVE MOTION

- PRIMARY ORBIT TRANSFER AND RENDEZVOUS METHOD.
- DEPLOYMENT OR RETRIEVAL REQUIRES INCREMENTS OF ONE ORBITAL PERIOD FOR PLACEMENT TIME.
- FOR DEPLOYMENT TO 100NM IN ONE ORBIT PERIOD A 72 FT/SEC TOTAL DELTA V IS REQUIRED.
- TIME REQUIREMENTS DICTATE ENERGY REQUIRED FOR DEPLOYMENT OR RETRIEVAL.
- VBAR ΔV CHARACTERISTIC IS THAT IF THE VEHICLE IS NOT STOPPED AT THE VBAR LINE IT WILL CONTINUE TO LOOP AWAY FROM THE POINT OF DEPLOYMENT.

TRW DEFENSE SYSTEMS GROUP

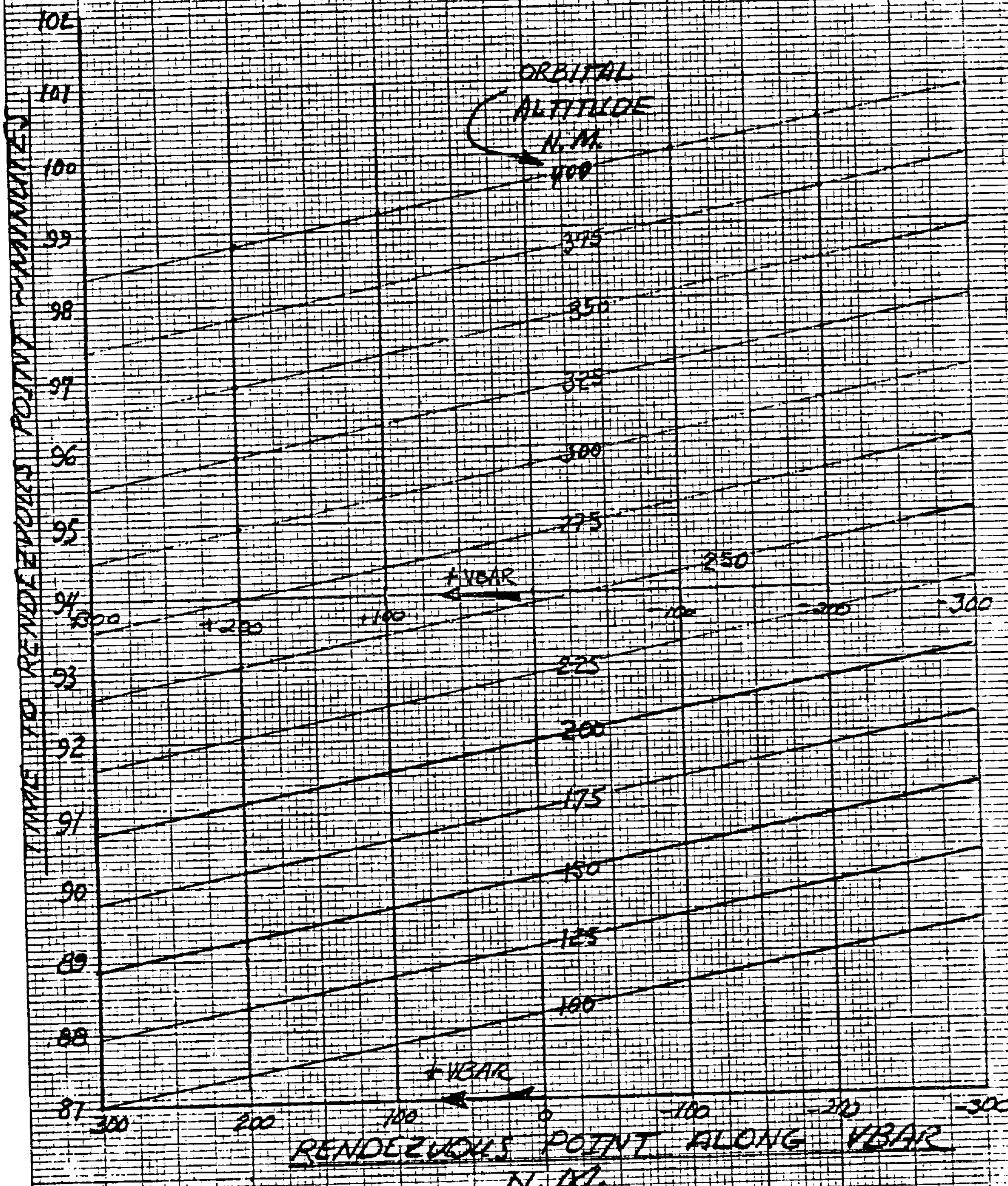
VBAR DELTA V RELATIVE MOTION





VBAR VELOCITY DIFFERENCE TO INITIATE RENDEZVOUS
ALONG VBAR LINE
± VELOCITY DELTA
FPS
REQUIRED
100
80
60
40
20
-20
-40
-60
-80
-100
+VBAR
-VBAR
200 180 160 140 120 100 80 60 40 20
-20 -40 -60 -80 -100 -120 -140 -160 -180 -200
DISTANCE TO RENDEZVOUS
NM
H=400 NM
H=100 NM
H=100 NM
H=400 NM
ENERGY REQUIREMENTS
TO RENDEZVOUS
JULY 12, 1984

TIME TO RENDEZVOUS POINT
IN ONE REVOLUTION
USING ΔV ALONG VBAR



C. RBAR DELTA V RELATIVE MOTION

- IF ΔV IN RBAR DIRECTION USED FOR DEPLOYMENT OR RETRIEVAL ONLY ONE HALF ORBITAL PERIOD IS REQUIRED.

- FOR DEPLOYMENT TO 100NM IN ONE-HALF ORBIT PERIOD A 168 FT/SEC TOTAL DELTA V IS REQUIRED.

- COMPARISON WITH VBAR ΔV TO PLACE FORMATION FLYER 50 NAUTICAL MILES OUT AT 250NM ORBITAL ALTITUDE;

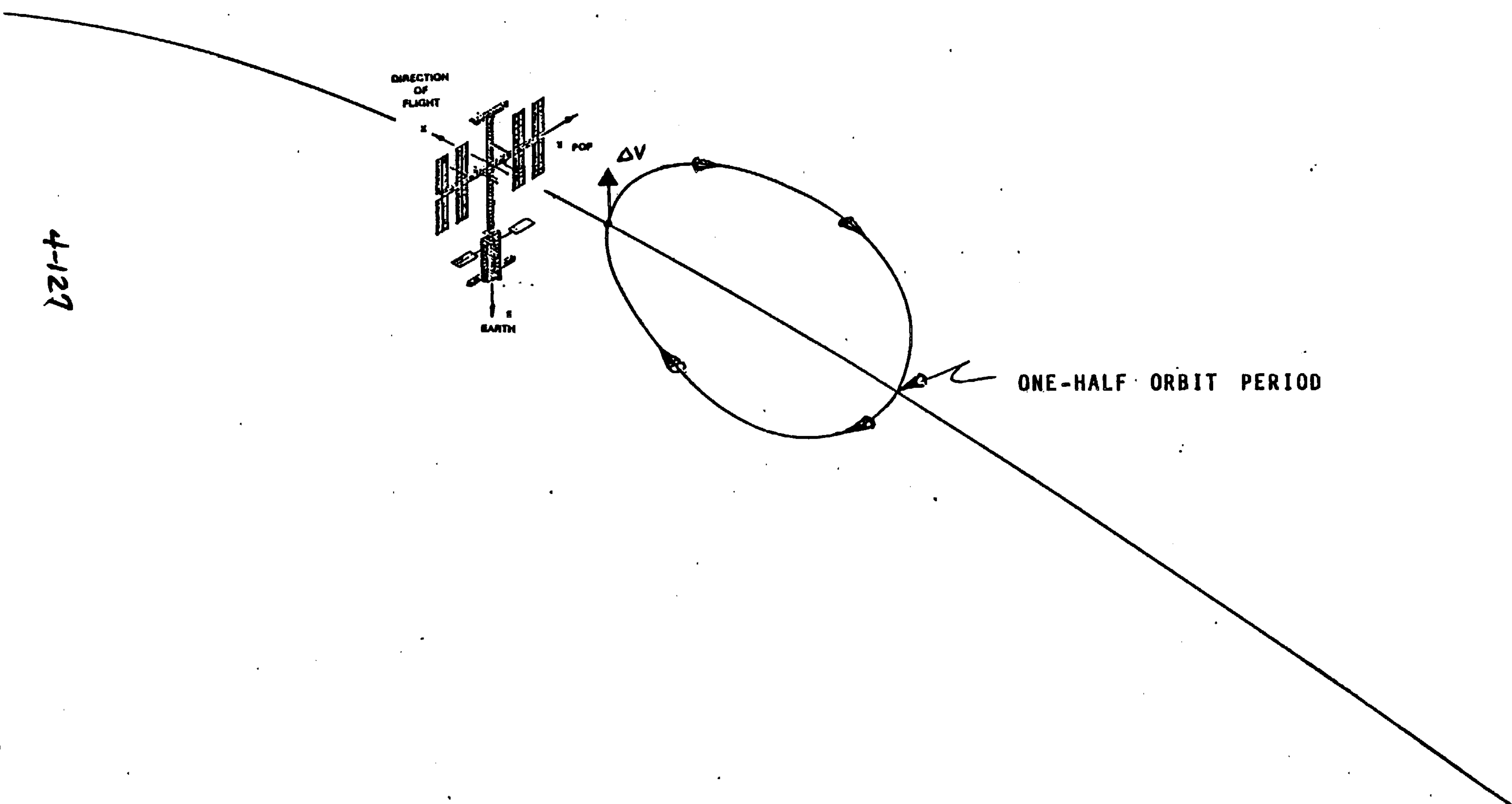
  VBAR ΔV = 38 FT/SEC IN 95 MINUTES

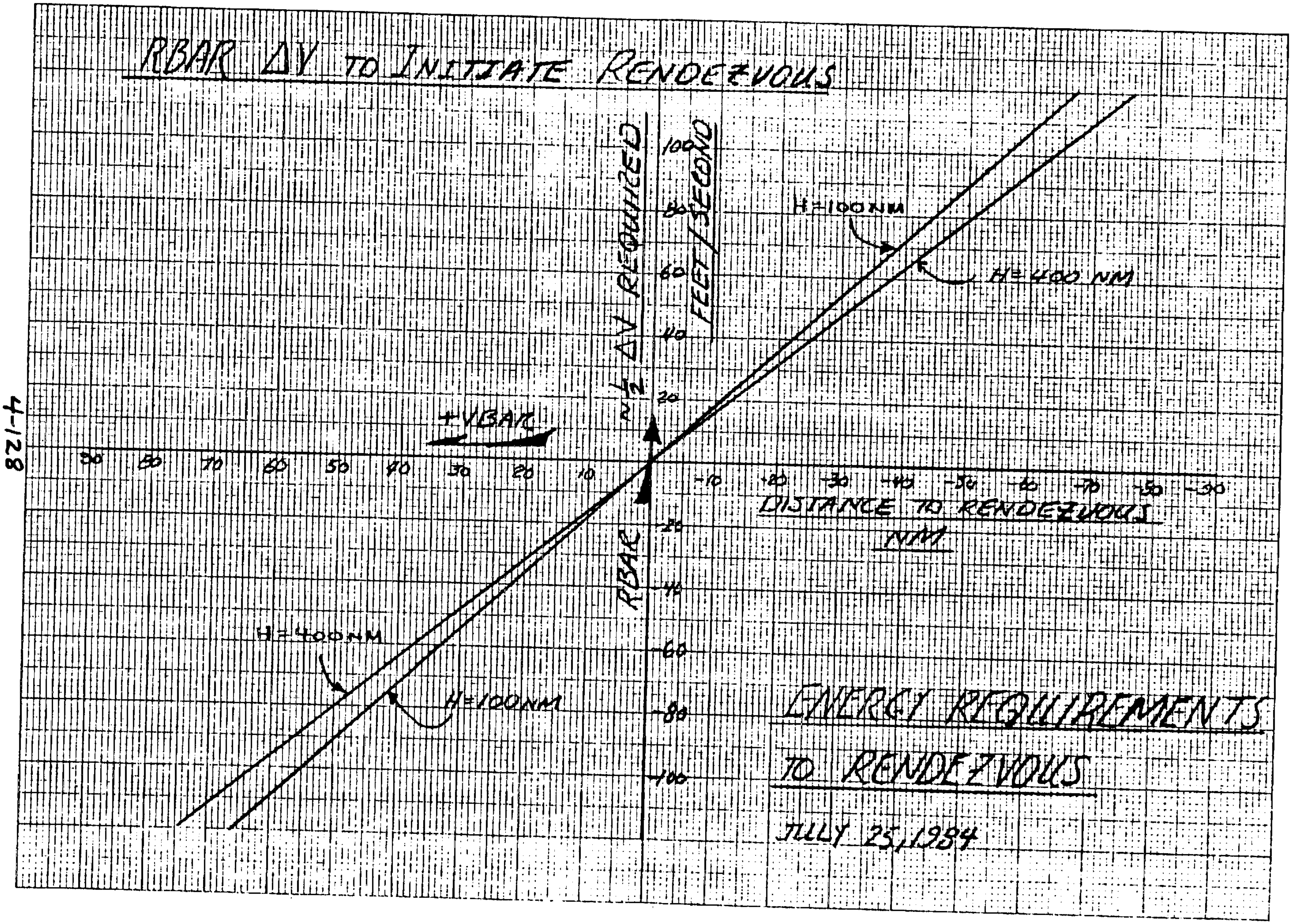
  RBAR ΔV = 170 FT/SEC IN 47.5 MINUTES

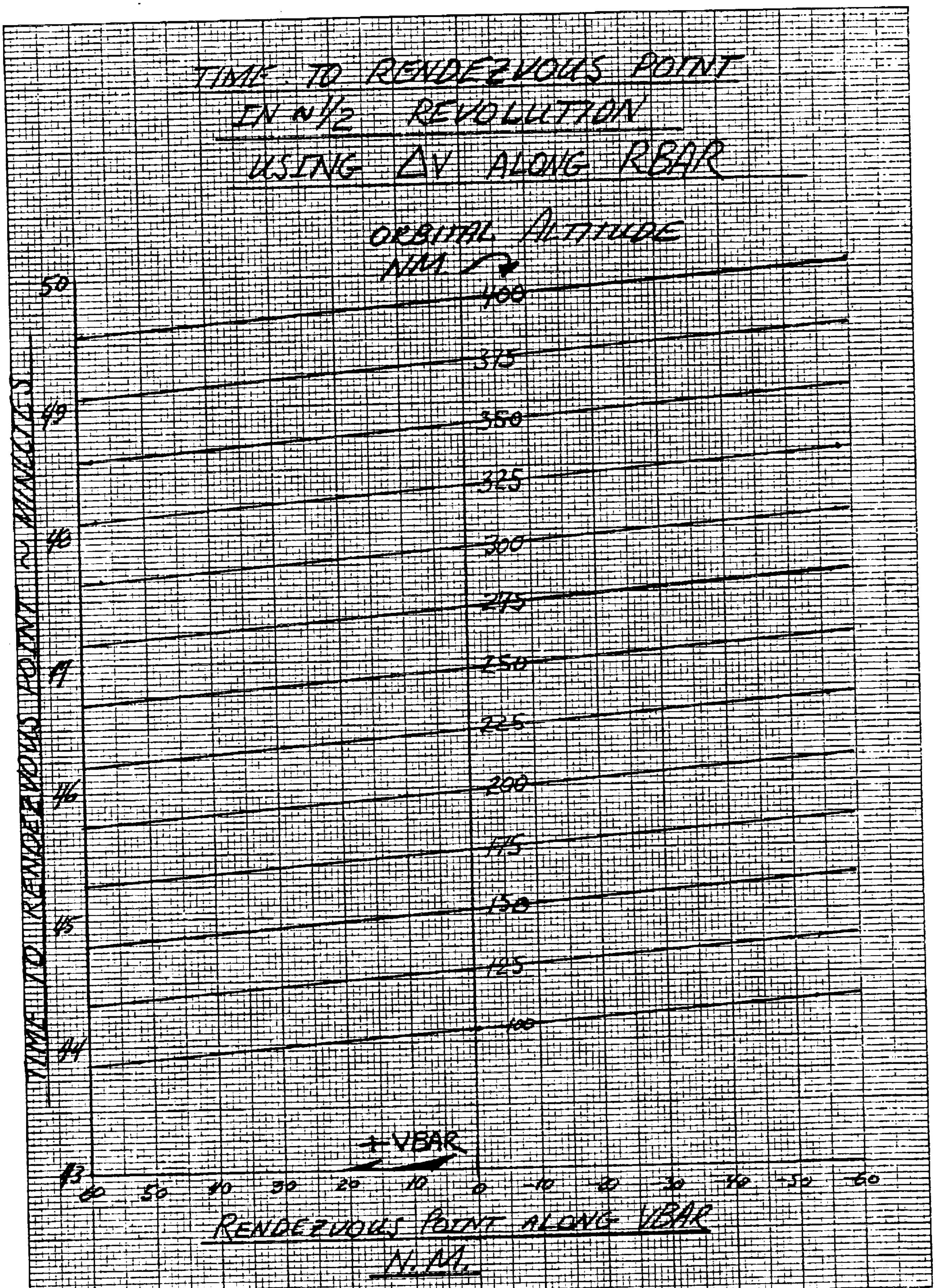
- RBAR ΔV CHARACTERISTIC IS THAT IF THE VEHICLE IS NOT STOPPED AT VBAR LINE IT WILL RETURN AND PASS NEAR THE POINT OF DEPLOYMENT.

TRW DEFENSE SYSTEMS GROUP

RBAR DELTA V RELATIVE MOTION




RBAR ΔV TO INITIATE RENDEZVOUS
≈ 1/2 ΔV REQUIRED
FEET/SECOND
100
80
60
40
20
-20
-40
-60
-80
-100
H=100NM
H=400 NM
+VBAR
90
80
70
60
50
40
30
20
10
-10
-20
-30
-40
-50
-60
-70
-80
-90
DISTANCE TO RENDEZVOUS
NM
RBAR
H=400NM
H=100NM
ENERGY REQUIREMENTS
TO RENDEZVOUS
JULY 25, 1984

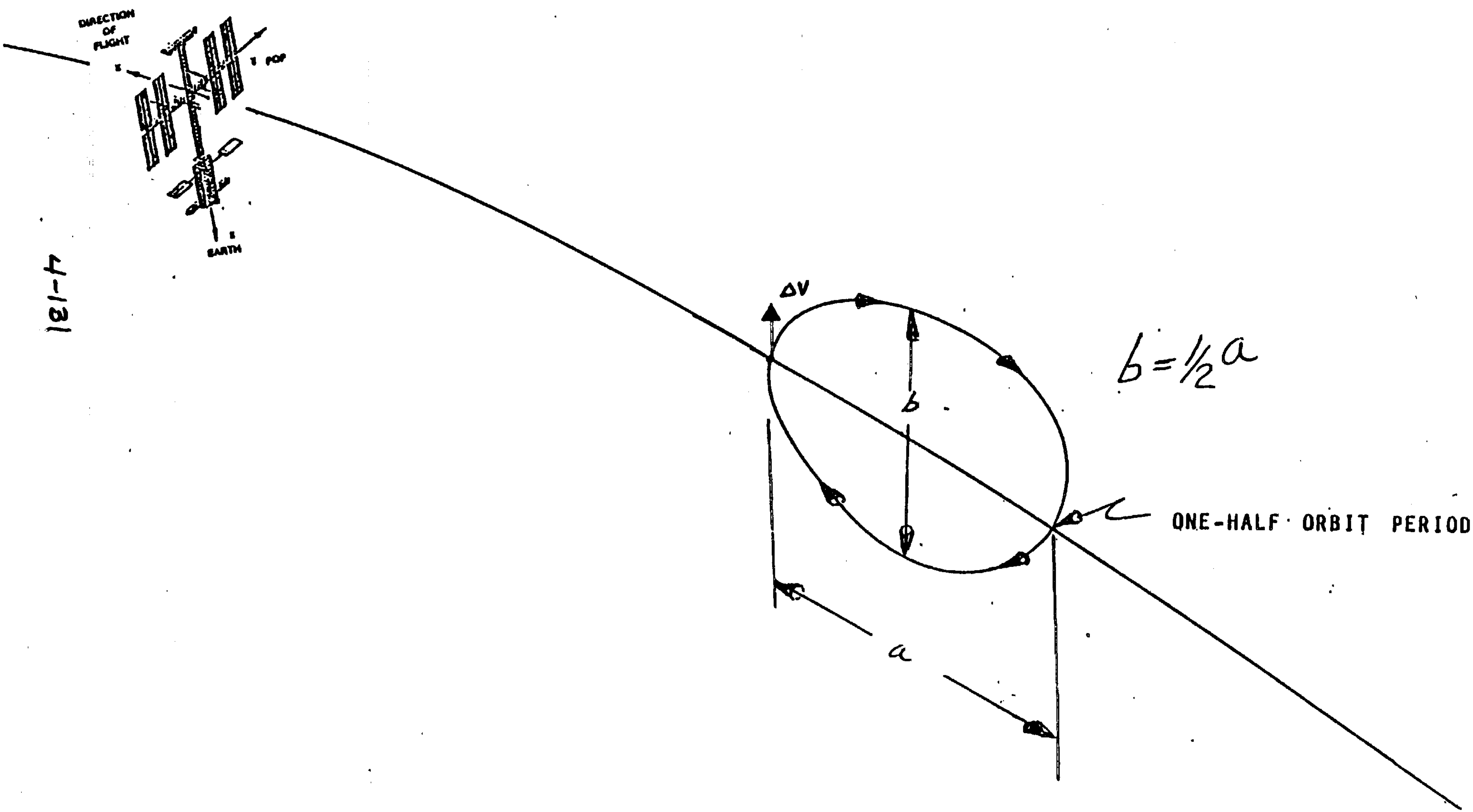

TIME TO RENDEZVOUS POINT
IN N1/2 REVOLUTION
USING ΔV ALONG RBAR
ORBITAL ALTITUDE
N.M.
400
375
350
325
300
275
250
225
200
175
150
125
100
50
49
48
47
46
45
44
43
TIME TO RENDEZVOUS POINT ~ MINUTES
+VBAR
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
RENDEZVOUS POINT ALONG VBAR
N.M.

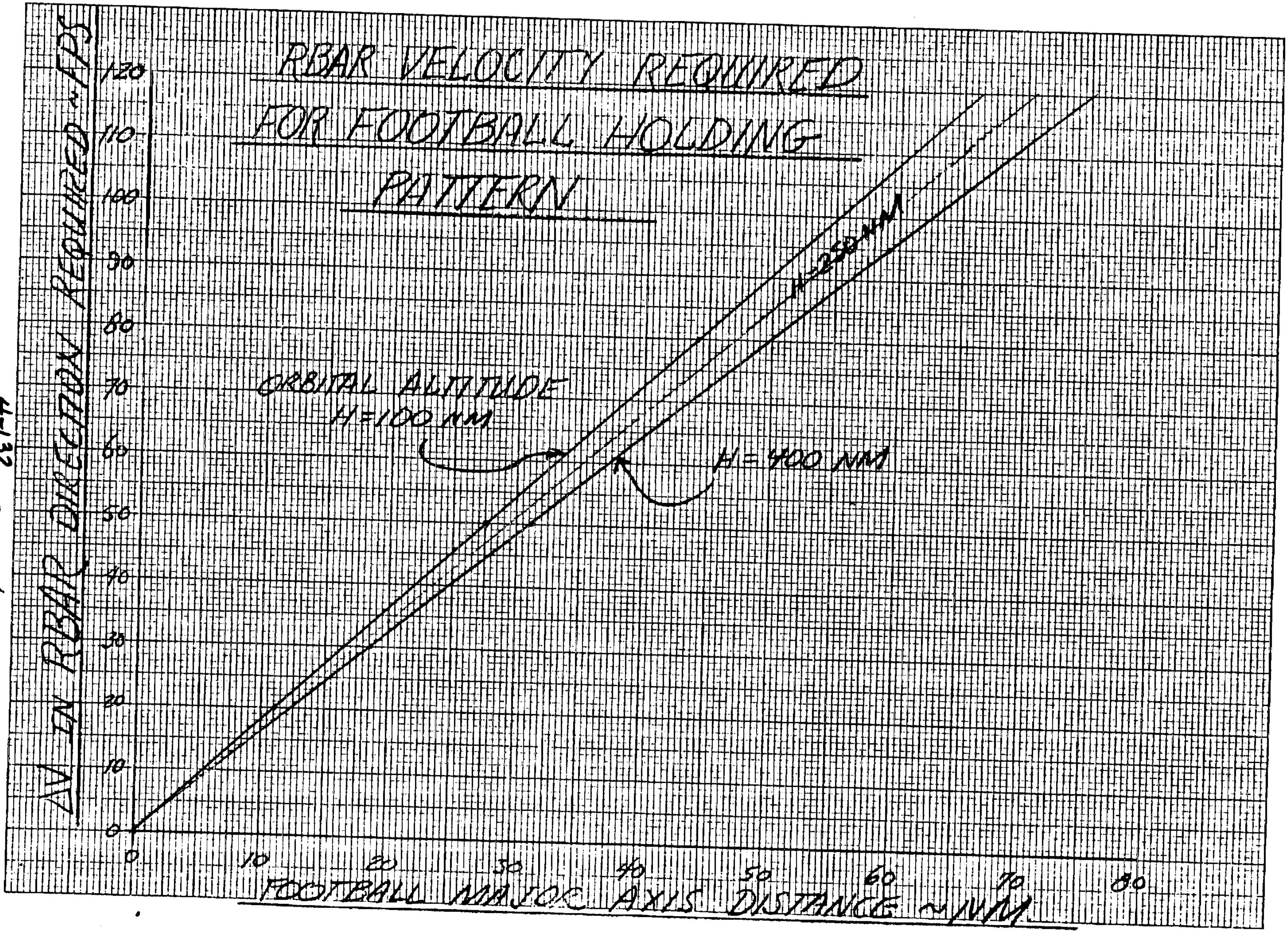
D. THE EQUAL PERIOD RELATIVE MOTION FOOTBALL

- PRIMARY METHOD TO PLACE VEHICLE INTO THE FORMATION.
- DEPLOYMENT INTO RELATIVE MOTION FOOTBALL FROM AN EQUAL PERIOD ORBIT POSITION IS DONE WITH A ΔV IN THE $\pm$ RBAR DIRECTION.
- FOR DEPLOYMENT INTO A 20NM FOOTBALL, 34 FT/SEC DELTA V IS REQUIRED.
- THE RATIO OF MINOR AXIS LENGTH TO MAJOR AXIS LENGTH IS 0.5 FOR ORBITING VEHICLES. THE VEHICLE WILL RISE ABOVE THE VBAR LINE 0.25 THE DISTANCE IT MOVES BEHIND (OR AHEAD) THE POINT OF DEPLOYMENT.
- THE EQUAL PERIOD RELATIVE MOTION FOOTBALL FACILITATES THE PLACEMENT OF MULTIPLE FORMATION FLYERS AT THE SAME DISTANCE FROM THE SPACE STATION.

TRW DEFENSE SYSTEMS GROUP

THE EQUAL PERIOD RELATIVE MOTION FOOTBALL

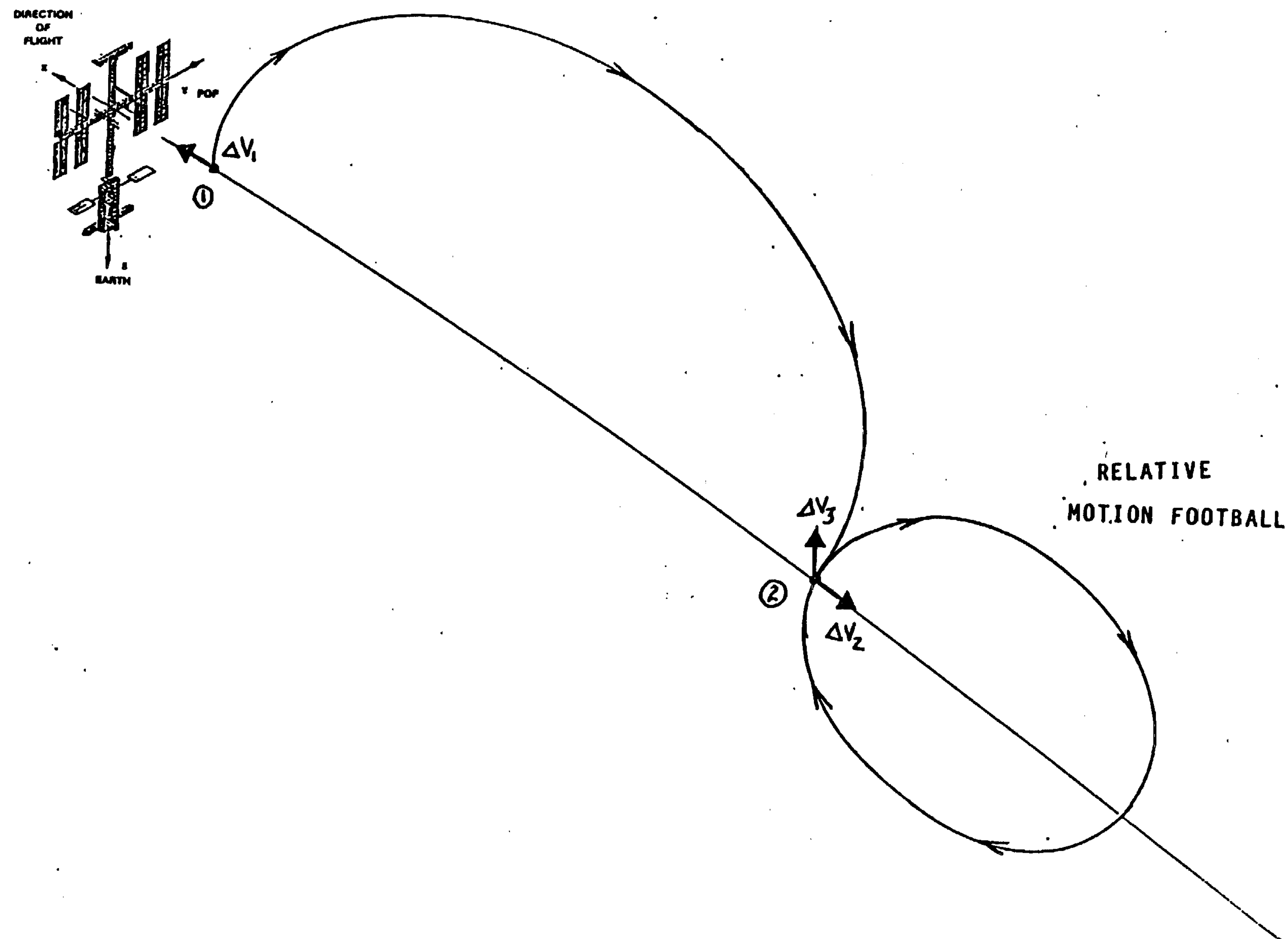



RBAR VELOCITY REQUIRED
FOR FOOTBALL HOLDING
PATTERN
ORBITAL ALTITUDE
H=100 NM
H=250 NM
H=400 NM
ΔV IN RBAR DIRECTION REQUIRED ~ FPS
0
10
20
30
40
50
60
70
80
90
100
110
120
FOOTBALL MAJOR AXIS DISTANCE ~ NM

C-7

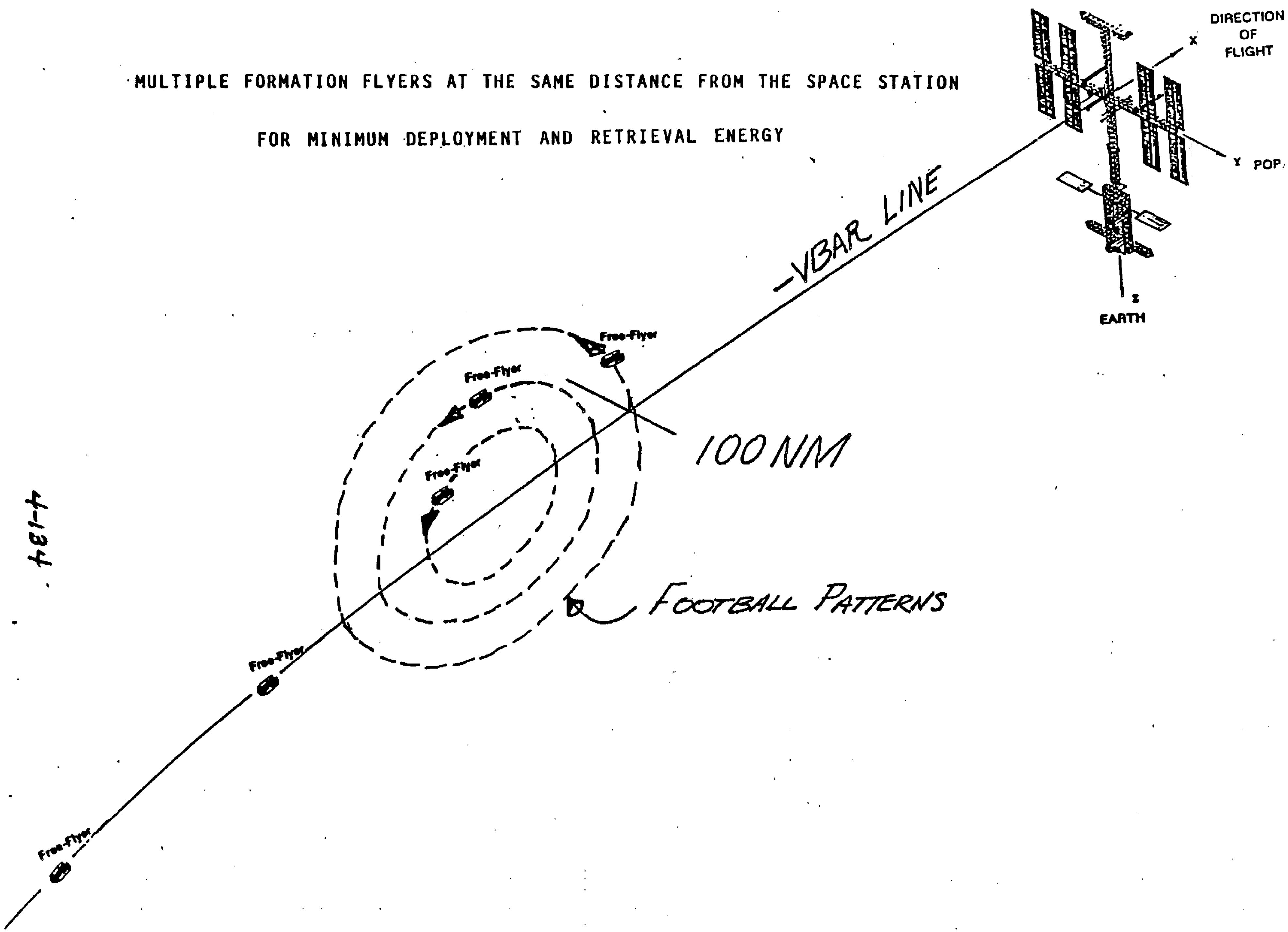
DEPLOYMENT STRATEGIES

METHOD TO PLACE VEHICLE INTO THE FORMATION



MULTIPLE FORMATION FLYERS AT THE SAME DISTANCE FROM THE SPACE STATION

FOR MINIMUM DEPLOYMENT AND RETRIEVAL ENERGY



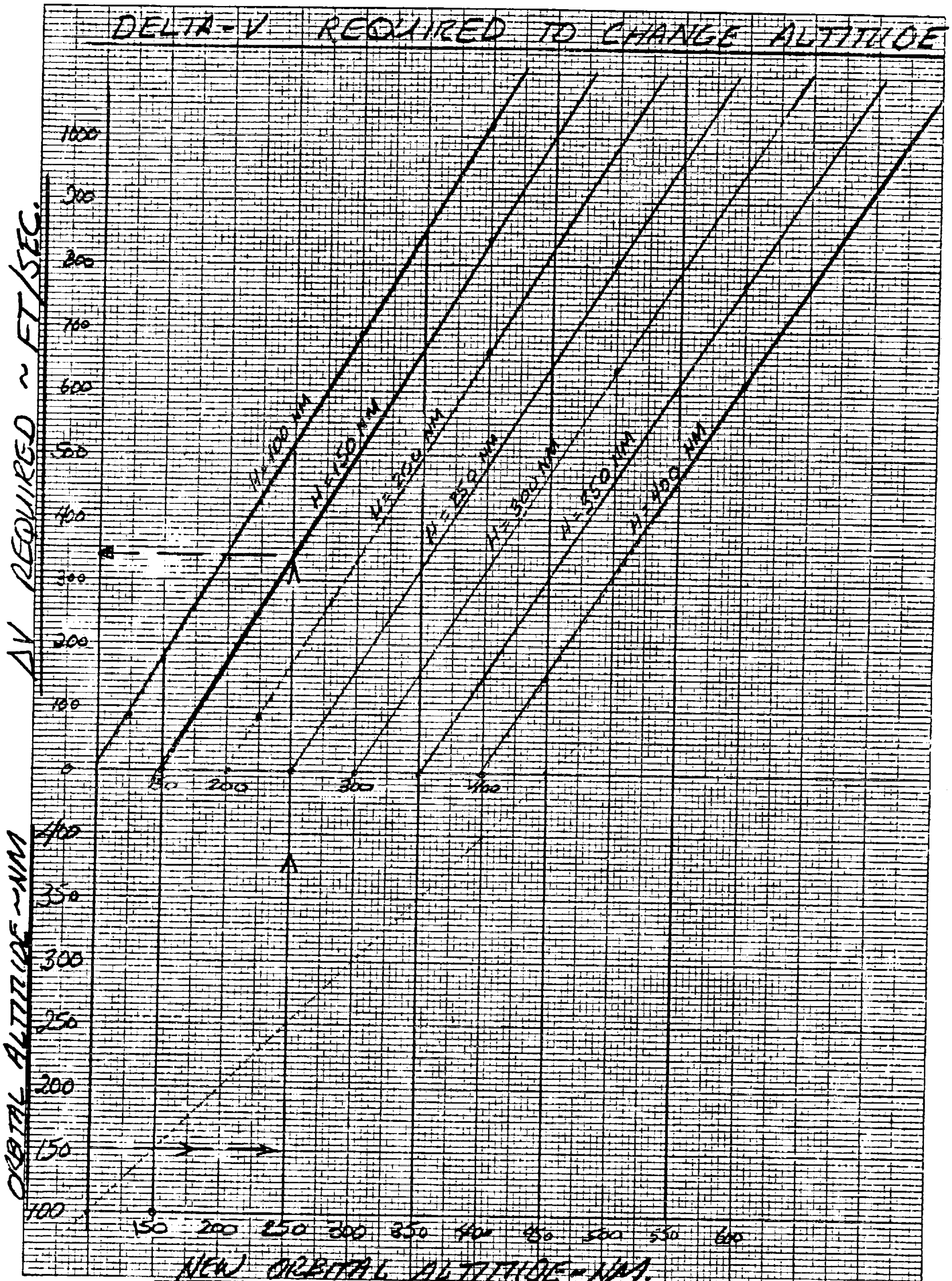
E. ENERGY REQUIRED TO CHANGE ORBITAL ALTITUDE

- ORBITAL ALTITUDE CHANGES ARE NOT ONLY EXPENSIVE BUT REQUIRE PHASING MANEUVERS TO RENDEZVOUS.

- TO GO FROM A 150NM ORBIT TO A 250NM ORBIT REQUIRES 340 FT/SEC TOTAL DELTA V.

- FORMATION FLYERS ARE RECOMMENDED TO BE LOCATED IN TRAFFIC ZONES 5 AND 6 NEAR THE VBAR LINE (AT STATION ALTITUDE).

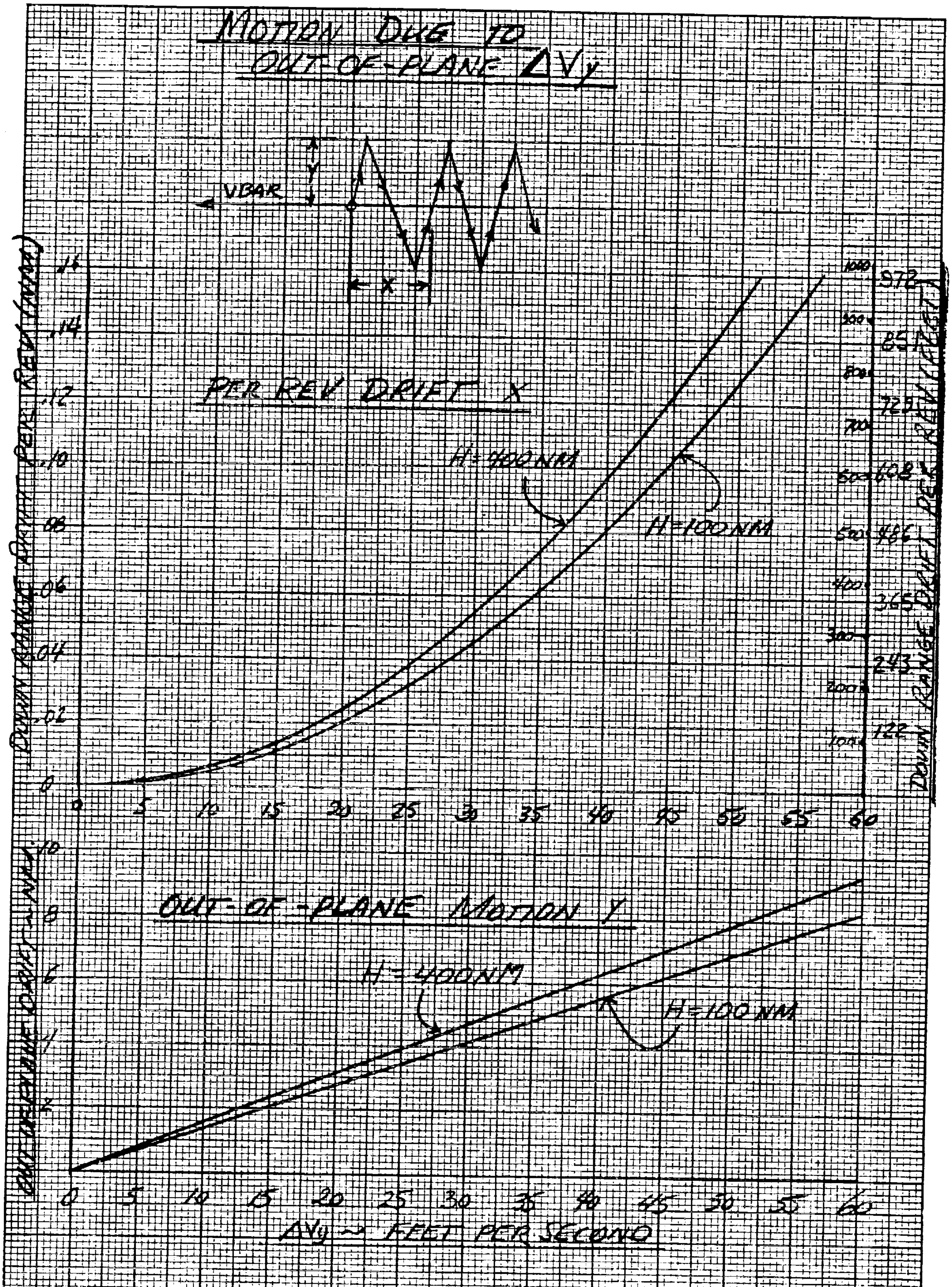
TRW DEFENSE SYSTEMS GROUP


DELTA-V REQUIRED TO CHANGE ALTITUDE
ΔV REQUIRED ~ FT/SEC.
ORBITAL ALTITUDE ~NM
NEW ORBITAL ALTITUDE ~NM.
H=100 NM
H=150 NM
H=200 NM
H=250 NM
H=300 NM
H=350 NM
H=400 NM
1000
900
800
700
600
500
400
300
200
100
0
150
200
250
300
350
400
450
500
550
600
100

F. OUT-OF-PLANE FORMATION MOTION

- OUT-OF-PLANE ΔV CAUSES SLIGHT CHANGE IN ORBITAL PERIOD WHICH WILL CAUSE FORMATION FLYER TO DRIFT DOWN RANGE. CORRECTABLE BY ANGLING THE ΔV SLIGHTLY AFT TO MAKE UP FOR THIS DRIFT.
- ENERGY REQUIREMENTS ARE HIGH FOR SMALL X-RANGE DISTANCES, I.E. FOR 5NM X-RANGE, 34 FT/SEC DELTA V IS REQUIRED.
- CAN BE USED TO SEPARATE FORMATION FLYERS WHEN VEHICLE DENSITIES ARE HIGH.

TRW DEFENSE SYSTEMS GROUP



MOTION DUE TO
OUT-OF-PLANE ΔVy
VBAR
Y
X
PER REV DRIFT X
H=400NM
H=100NM
DOWN RANGE DRIFT PER REV (NM)
DOWN RANGE DRIFT PER REV (FEET)
0
.02
.04
.06
.08
.10
.12
.14
.16
100
122
200
243
300
365
400
486
500
608
600
729
700
800
851
900
972
1000
0 5 10 15 20 25 30 35 40 45 50 55 60
OUT-OF-PLANE MOTION Y
H=400NM
H=100NM
OUT OF PLANE DRIFT ~ NM
0
2
4
6
8
10
0 5 10 15 20 25 30 35 40 45 50 55 60
ΔVy ~ FEET PER SECOND

ORBITAL MAINTENANCE

A. ORBITAL PERTURBATIONS CAUSING FORMATION FLYERS TO DRIFT

- THE DIFFERENCE IN BALLISTIC COEFFICIENTS OF SPACE STATION AND FORMATION FLYER CAUSE GREATEST DEVIATION FROM DESIGNED RELATIVE MOTION ORBITS.

  - UP-RANGE DRIFT IS APPROXIMATED BY

$$\boxed{X(t) = X(t_o) + C(H)\ (B - B_s)\ (t - t_o)^2}$$

WHERE

$X(t)$ - UP RANGE DISTANCE AT TIME t

$X(t_o)$ - UP RANGE DEPLOYMENT DISTANCE AT TIME t_o

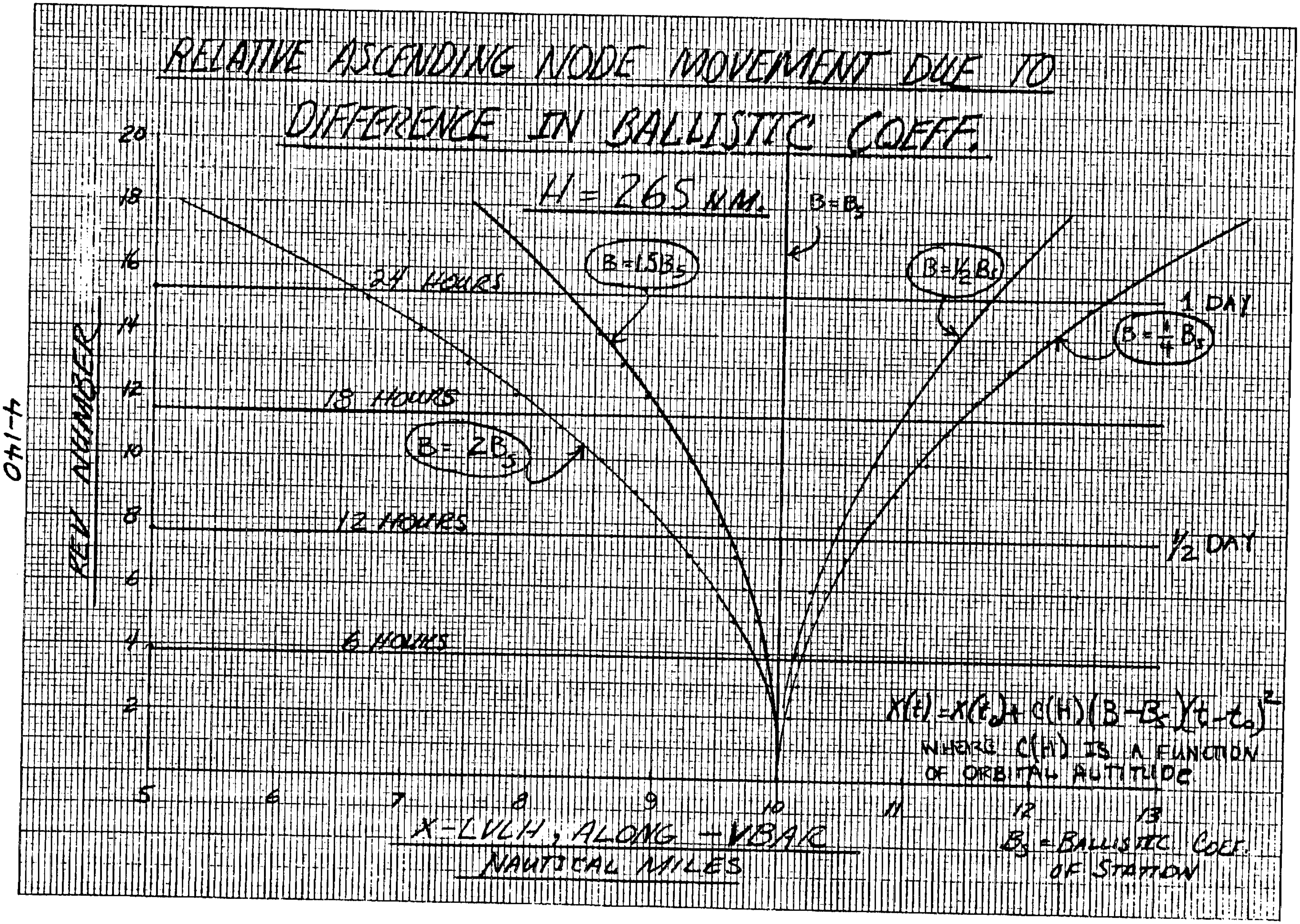
$C(H)$ - A CONSTANT DEPENDING ON ORBIT ALTITUDE, ATMOSPHERE DENSITY AND PHYSICAL UNITS USED

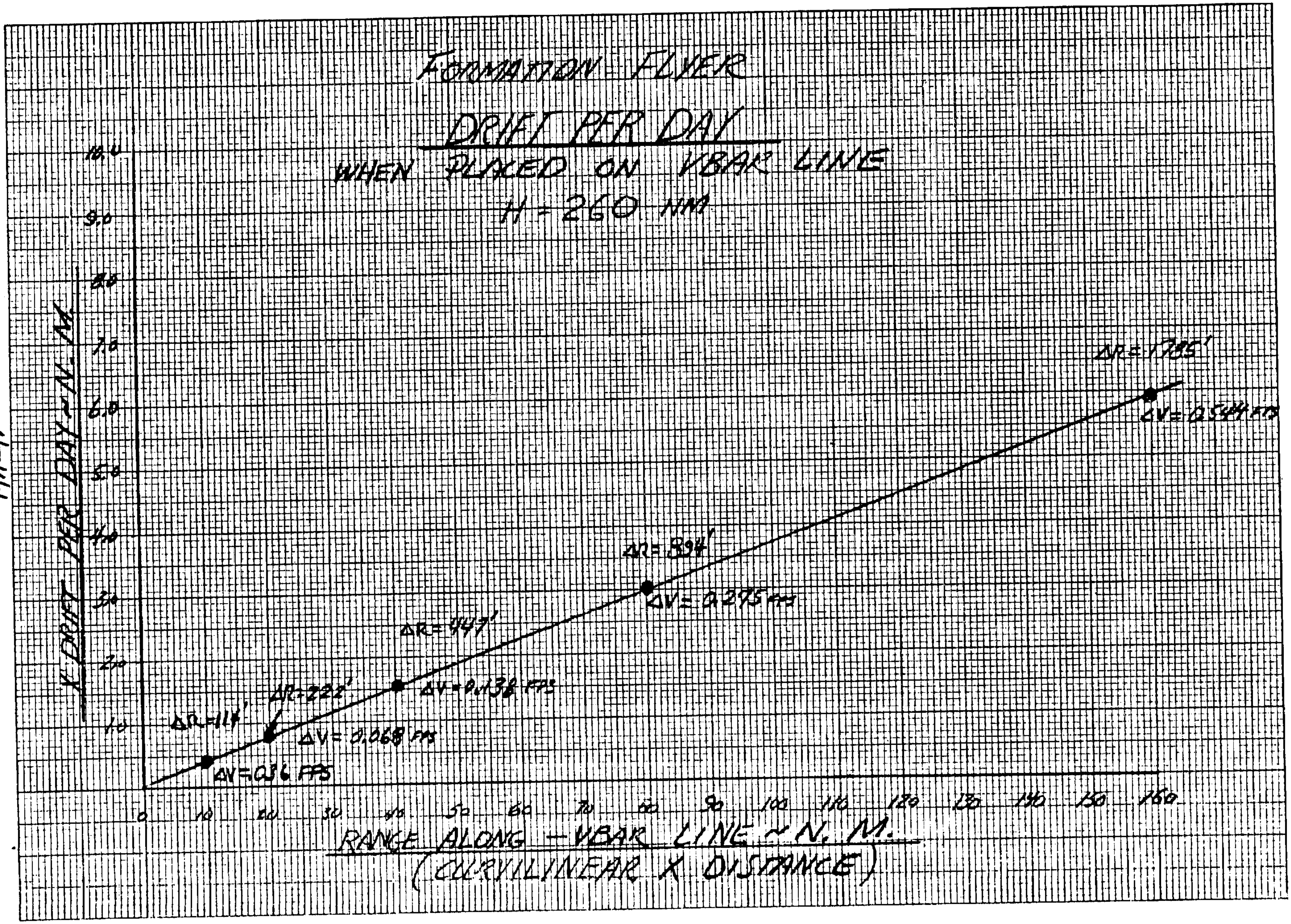
B_S - BALLISTIC COEFFICIENT OF SPACE STATION $\left(\frac{C_D S}{W}\right)$

B - BALLISTIC COEFFICIENT OF FORMATION FLYER

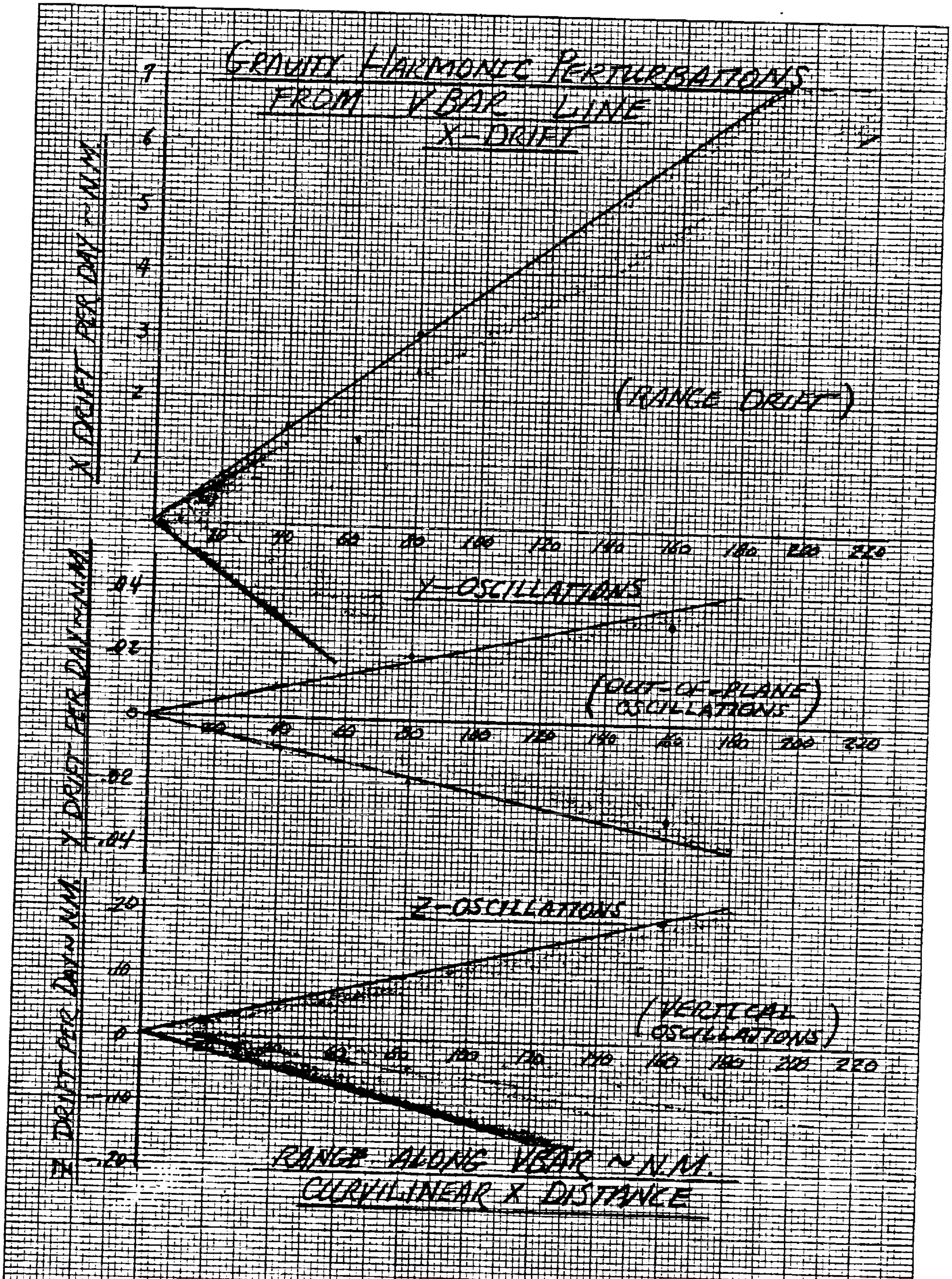
t - TIME (IN DAYS)

TRW DEFENSE SYSTEMS GROUP


RELATIVE ASCENDING NODE MOVEMENT DUE TO
DIFFERENCE IN BALLISTIC COEFF.
H = 265 N.M.
REV NUMBER
X-LVLH, ALONG -VBAR
NAUTICAL MILES
24 HOURS
18 HOURS
12 HOURS
6 HOURS
1 DAY
1/2 DAY
B = 2Bs
B = 1.5Bs
B = Bs
B = 1/2 Bs
B = 1/4 Bs
X(t) = X(to) + C(H)(B - Bs)(t - to)²
WHERE C(H) IS A FUNCTION
OF ORBITAL ALTITUDE
Bs = BALLISTIC COEF.
OF STATION



FORMATION FLYER
DRIFT PER DAY
WHEN PLACED ON VBAR LINE
H = 260 NM
X DRIFT PER DAY ~ N. M.
RANGE ALONG – VBAR LINE ~ N. M.
(CURVILINEAR X DISTANCE)
ΔR = 111'
ΔV = 0.36 FPS
ΔR = 222'
ΔV = 0.068 FPS
ΔR = 447'
ΔV = 0.138 FPS
ΔR = 894'
ΔV = 0.275 FPS
ΔR = 1785'
ΔV = 0.544 FPS

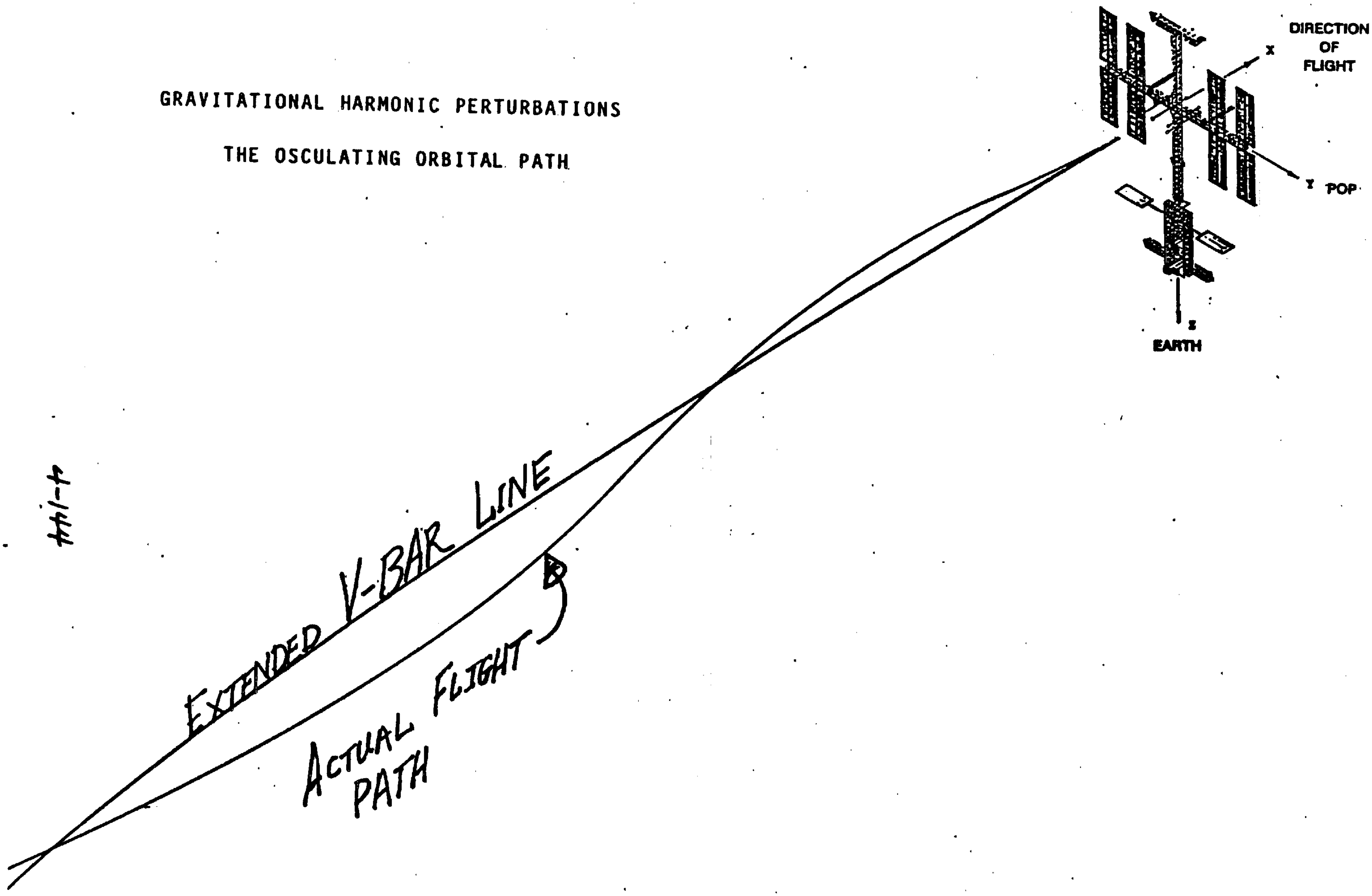

GRAVITY HARMONIC PERTURBATIONS FROM VBAR LINE
X-DRIFT
X DRIFT PER DAY ~ N.M.
(RANGE DRIFT)
Y-OSCILLATIONS
Y DRIFT PER DAY ~ N.M.
(OUT-OF-PLANE OSCILLATIONS)
Z-OSCILLATIONS
Z DRIFT PER DAY ~ N.M.
(VERTICAL OSCILLATIONS)
RANGE ALONG VBAR ~ N.M.
CURVILINEAR X DISTANCE

- GRAVITATIONAL HARMONIC PERTURBATIONS
    - THE OSCULATING ORBITAL PATH
    - CAUSES RANGE DRIFT WHEN PLACED ON VBAR LINE AT THE SAME VELOCITY OF THE STATION
    - ACCURATELY PLACED FORMATION FLYERS ON OSCULATING ORBITAL PATH HAVE OSCILLATORY RELATIVE MOTIONS WITH AMPLITUDES INCREASING AS RELATIVE RANGE INCREASES
- VARIATIONS IN DENSITY DUE CHANGES IN THE SOLAR FLUX AND GEOMAGNETIC INDEX CAUSE PRONOUNCED EFFECTS ON THE DRAG PERTURBATIONS. THE 11-YEAR SOLAR CYCLE CAUSES 50% CHANGE IN DENSITY AT 200NM.
- VARIATIONS IN SPACE STATION ATTITUDE CAUSE DIFFERENT FRONTAL AREAS TO BE PRESENTED TO THE AERODYNAMIC SLIP STREAM. WITH CURRENT SPACE STATION CONFIGURATIONS, THIS WILL CAUSE LARGE VARIATIONS IN THE STATION BALLISTIC COEFFICIENT, HENCE DRIFT RATES OF ALL FORMATION FLYERS WILL VARY.

TRW DEFENSE SYSTEMS GROUP

GRAVITATIONAL HARMONIC PERTURBATIONS

THE OSCULATING ORBITAL PATH



B. ΔV REQUIREMENTS TO MAINTAIN ORBITS

- OPERATIONAL PROCEDURES MUST BE DEVELOPED TO COMPENSATE FOR LARGE DRAG DISPERSIONS DUE TO SPACE STATION CONFIGURATION.

- SMALL INCREMENTS OF ENERGY COULD BE ADDED (OR SUBTRACTED) FROM THE FORMATION FLYERS ORBIT TO MAINTAIN RELATIVE POSITION WITHIN BOUNDS.

- THESE ΔV CORRECTIONS SHOULD BE MADE AT THE TIME THE FORMATION FLYER PASS NEAR THE VBAR LINE, HOWEVER, GUIDANCE PROGRAMS MUST BE DEVELOPED TO OPTIMIZE THIS PROCESS.

- THE MAGNITUDE OF THE ΔV REQUIRED CAN BE BASED UPON THE PREDICTED DRIFT DUE TO THE DIFFERENCE BETWEEN STATION AND FORMATION FLYER BALLISTIC COEFFICIENTS,

$$\Delta X = X(t) - X(t_o) = C(H)\,(B - B_s)\,(t - t_o)^2$$

- THIS NON-LINEAR DRIFT CAN BE CANCELED BY A LINEAR MOVEMENT CAUSED BY A ΔV IN THE $\pm$VBAR DIRECTION AT SPECIFIC INTERVALS DURING THE FLIGHT; GIVEN BY, $\Delta V \cong 0.36\ \Delta X$.

  HERE ΔX IS IN NAUTICAL MILES AND ΔV IS FEET PER SECOND. FOR EXAMPLE, A 3NM DRIFT CAN BE CORRECTED BY A 1.08 FT/SEC VBAR ΔV. THIS CORRECTION WOULD HOLD THE FORMATION FLYER IN POSITION FOR APPROXIMATELY,

$$T \cong 1.41 \sqrt{\left|\frac{\Delta X}{C(H)\,(B - B_s)}\right|} \quad \text{(DAYS).}$$

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PRELIMINARY REQUIREMENTS

A. ORBITAL DYNAMICS

- OPERATIONAL PROCEDURES MUST BE DEVELOPED TO MAINTAIN RANGE TO THE SPACE STATION.
- FORMATION FLYING PATTERNS SHOULD BE CONCENTRIC RELATIVE MOTION FOOTBALL ORBITS PLACED ALONG THE FORE AND AFT OSCULATING ORBITAL PATH.
- TUNED BALLISTIC COEFFICIENTS WILL BE NECESSARY FOR MINIMUM ENERGY CONSIDERATIONS, I.E. FORMATION FLYER AREA AND WEIGHT SPECIFICATIONS MUST BE CONTROLLED.
- MINIMUM SEPARATION DISTANCES BETWEEN FORMATION FLYERS MUST BE ESTABLISHED FOR THE FORMATION PATTERNS SO THAT ORBITAL MAINTENANCE REQUIREMENTS CAN BE SIZED.
- DEPLOYMENT AND RETRIEVAL COSTS ARE DIRECTLY PROPORTIONAL TO THE DISTANCE AND SIZE OF THE FORMATION. THIS IS ESPECIALLY TRUE WHEN TIME FOR DEPLOYMENT AND RETRIEVAL MUST BE A MINIMUM.

PRELIMINARY REQUIREMENTS (CONTINUED)

B. NAVIGATION IMPLICATIONS

- STATION NAVIGATION/SENSOR SYSTEMS SHOULD BE PLANNED TO PROVIDE MINIMUM EQUIPMENT REQUIREMENTS ON FORMATION FLYERS.
- NAVIGATION SENSORS REQUIREMENTS ARE SENSITIVE TO FORMATION FLYING PATTERN DIMENSIONS AND DISTANCES.
- DISTANCES TO THE FORMATION FLYING PATTERNS IS ONE OF THE DRIVERS IN THE SELECTION OF TRACKING SENSORS TO BE USED, E.G.

● OPTICAL	(FUNCTION OF TARGET SIZE)	<200NM
● RADAR	(SKIN TRACKING)	<30NM
● RADAR	(WITH TRANSPONDER)	<300NM
● LASER SYSTEMS		<10NM
● GPS		NO RANGE LIMITATION

TRW DEFENSE SYSTEMS GROUP

C. FORMATION FLYER EQUIPMENT IMPLICATIONS

- SOME ΔV REQUIREMENTS WILL BE NECESSARY TO MAINTAIN ORBIT, HENCE SOME PROPULSION SYSTEM IS REQUIRED. PASSIVE FORMATION FLYERS WOULD BE FEASIBLE WITH USE OF AN ORBIT TRANSFER VEHICLE.
- AN ATTITUDE CONTROL SYSTEM IS REQUIRED FOR THRUST VECTOR CONTROL DURING CORRECTIVE BURN MANEUVERS AND WHATEVER ATTITUDE CONTROL REQUIRED DURING VEHICLE USE.
- SOME SENSOR AID MUST BE LOCATED ON THE FORMATION FLYER FOR MINIMUM NAVIGATION REQUIREMENTS.

TRW DEFENSE SYSTEMS GROUP

Lockheed
Engineering and Management
Services Company, Inc.

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TRAJECTORY CONTROL RENDEZVOUS

Fred D. Clark

Wolfram O. Mosebach

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PURPOSE OF STUDY

- o Design a rendezvous profile using onboard shuttle Guidance and Navigation.
- o Investigate feasibility of such a profile to support Space Traffic control close to the Space Station.
- o Identify modifications to shuttle Guidance and Navigation to enhance system performance.
- o Identify requirements on Space Station.

CONSTRAINTS

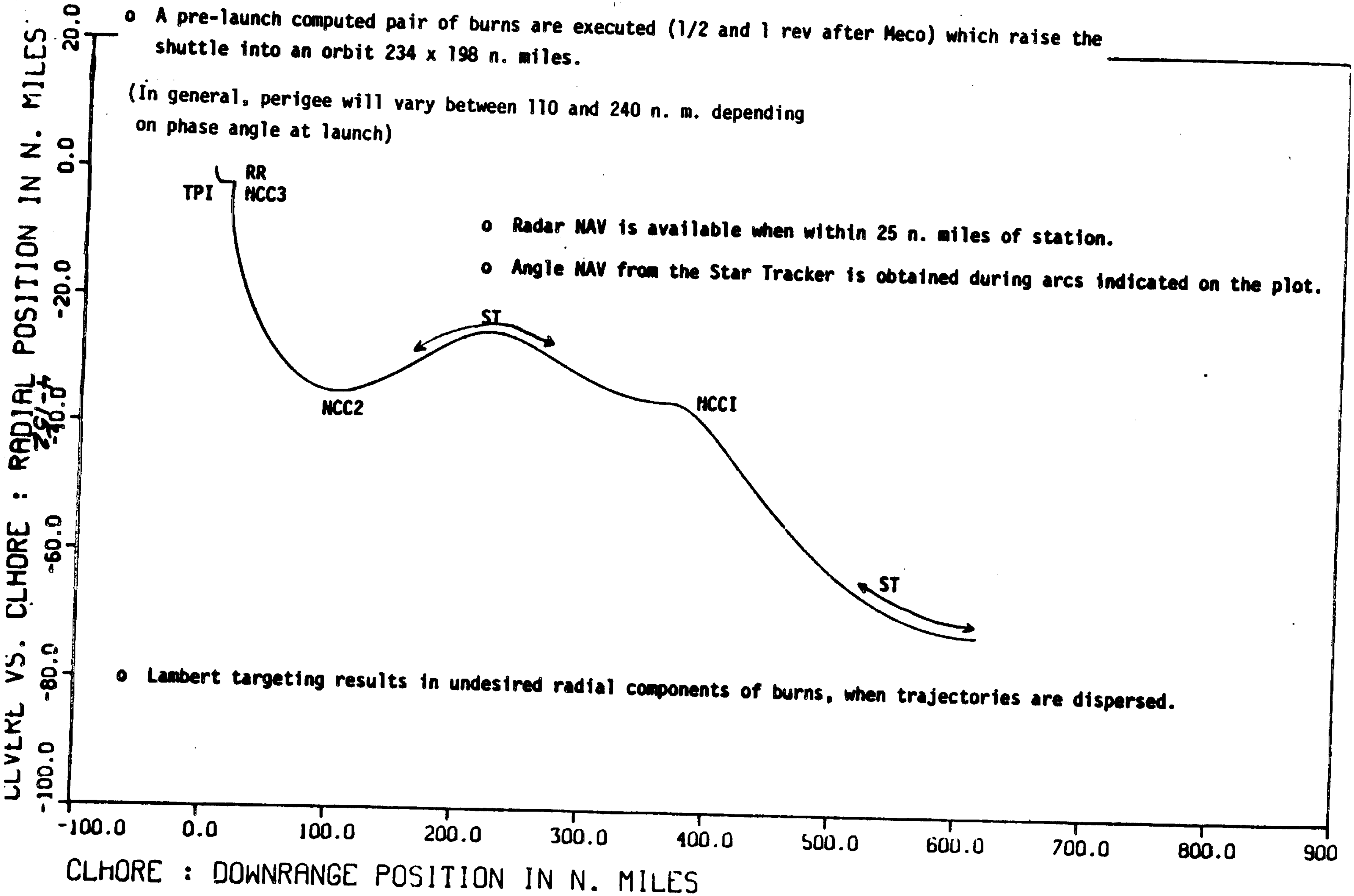
- o Assume rendezvous phase begins about 30 hours after launch with no ground state uplinks.
- o Shuttle will not reach the altitude of the Space Station until intercept, to support near station traffic and for safety.
- o Star tracker range limit of 700 nautical miles, Radar range limit of 25 nautical miles (300 nautical miles with transponder)
- o Direct insertion.

STUDY METHODOLOGY

- SPRINT - 3 DOF Simulation of current shuttle G&N; used for rendezvous G&N qualification of Shuttle
- State vector errors drawn from MECO dispersion covariance are propagated 16 revs
- Large filter covariance is used, otherwise no attempt has been made to tune filter for very long range
- Statistics computed from sample of 60 trajectories for each run
- Evaluate:
  - Current NAV and targeting (i.e. Lambert)
  - RR transponder and current targeting
  - GPS NAV and current targeting
  - Current NAV and NC-NH targeting

- Growth rate in downrange error is 23,000 feet per revolution (1 sigma)
- 1 sigma downrange dispersion at start of rendezvous is 360,000 feet

NOMINAL , LAMBERT TARGETED



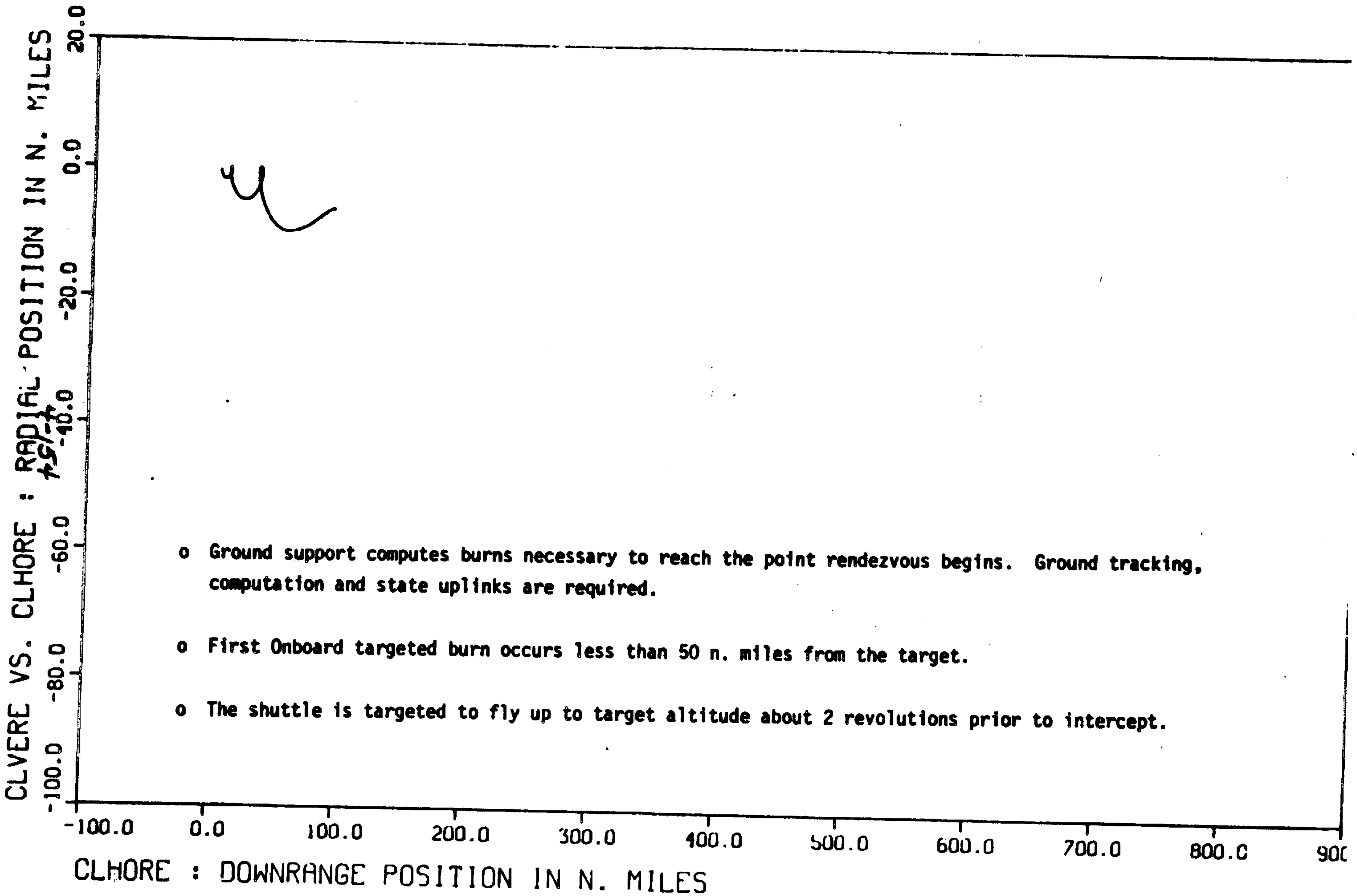
NOMINAL MANEUVER TABLE, LAMBERT TARGETING

BURN	TIME (Min)	HORIZ. ΔV (ft/sec)	
Pre-computed NC	-1435.0	285.1	
Pre-computed NH	-1388.7	7.2	
NCC1	46.0	79.8	
NCC2	129.4	39.8	
NCC3	179.4	55.0	
TPI	223.1	4.1	-2.4 radial
MC1	233.8	0.0	
MC2	248.8	0.0	
TPF	263.8	4.3	+1.2 radial

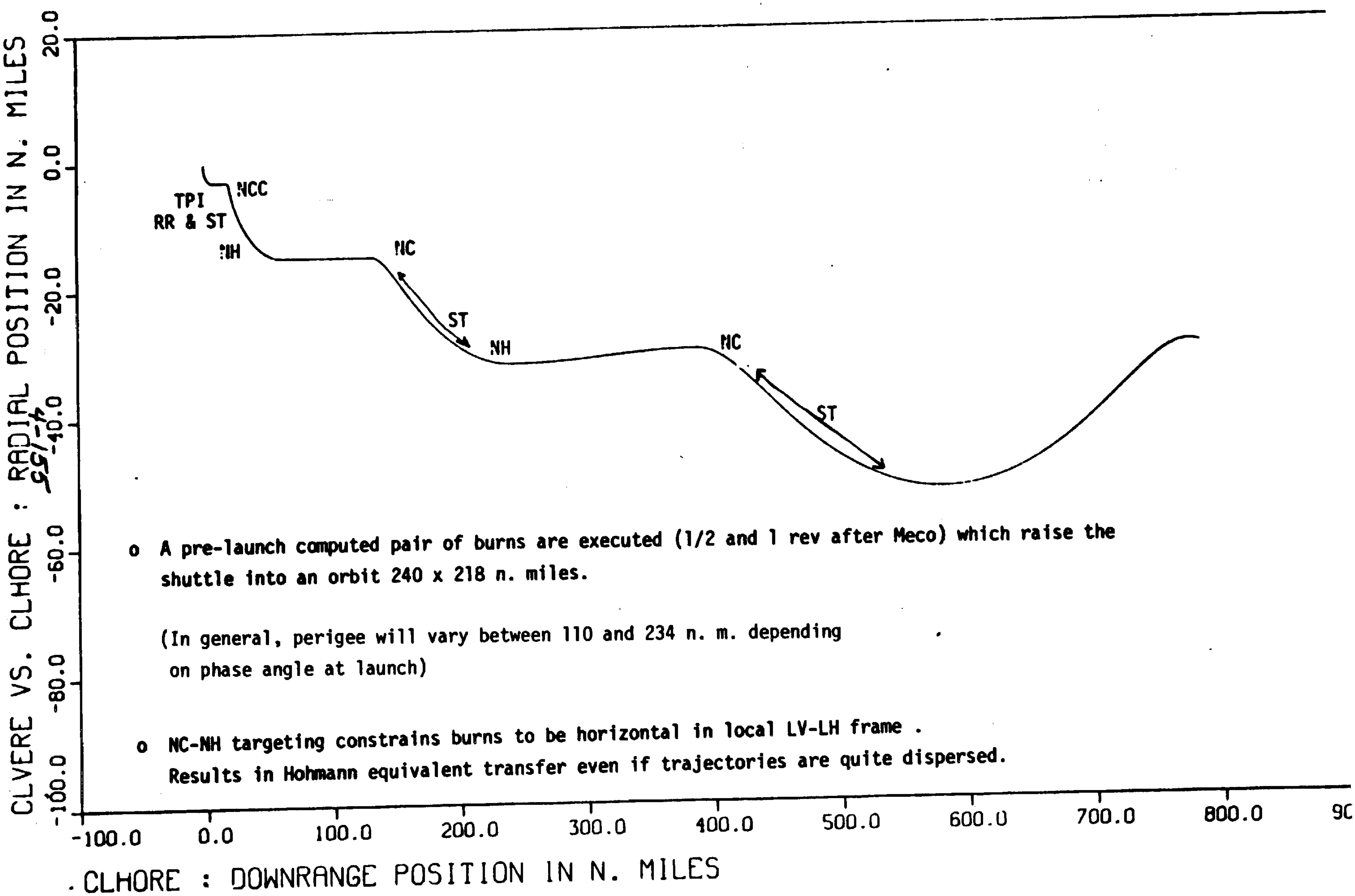
Total $|\Delta V|$ after rendezvous phase begins = 184.0 ft/sec

TOTAL $|\Delta V|$ = 476.3 ft/sec

BASELINE SHUTTLE RENDEZVOUS



NOMINAL , NC-NH TARGETED



- o A pre-launch computed pair of burns are executed (1/2 and 1 rev after Meco) which raise the shuttle into an orbit 240 x 218 n. miles.

  (In general, perigee will vary between 110 and 234 n. m. depending on phase angle at launch)

- o NC-NH targeting constrains burns to be horizontal in local LV-LH frame . Results in Hohmann equivalent transfer even if trajectories are quite dispersed.

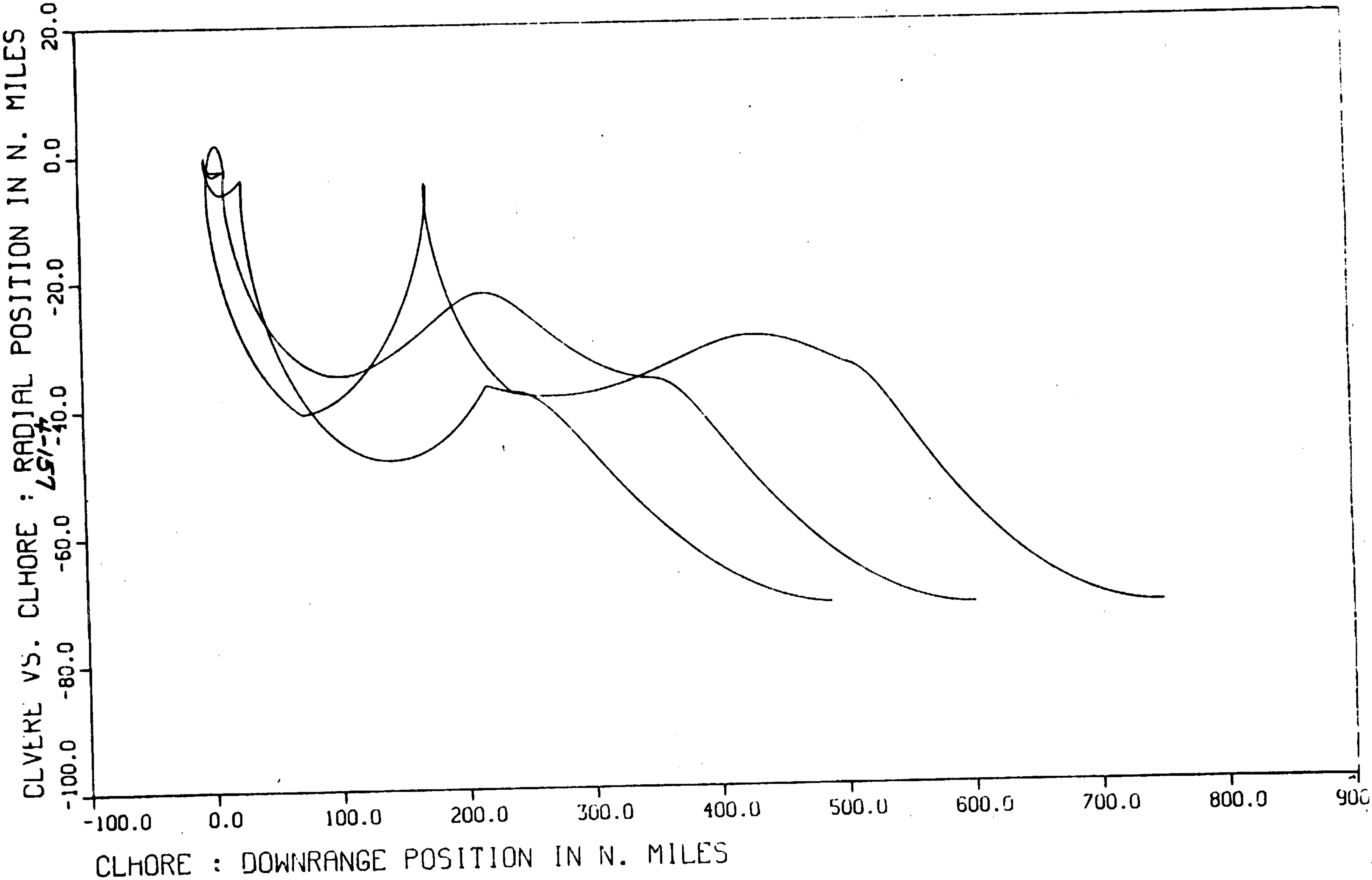
NOMINAL MANEUVER TABLE, NC-NH TARGETING

BURN	TIME (Min)	HORIZ. ΔV (ft/sec)	
Pre-computed NC	-1392.6	295.6	
Pre-computed NH	-1346.1	9.8	
NC1	96.1	34.4	
NH1	142.9	25.5	
NC2	189.7	28.9	
NH2	236.7	20.3	
NCC	283.9	20.2	
TPI	327.8	5.0	-3.1 radial
MC1	338.5	0.0	
MC2	353.5	0.0	
TPF	368.5	5.1	+1.5 radial

Total $|\Delta V|$ after rendezvous phase begins = 140.4 ft/sec

TOTAL $|\Delta V|$ = 445.8

CURRENT NAV & TARGETING



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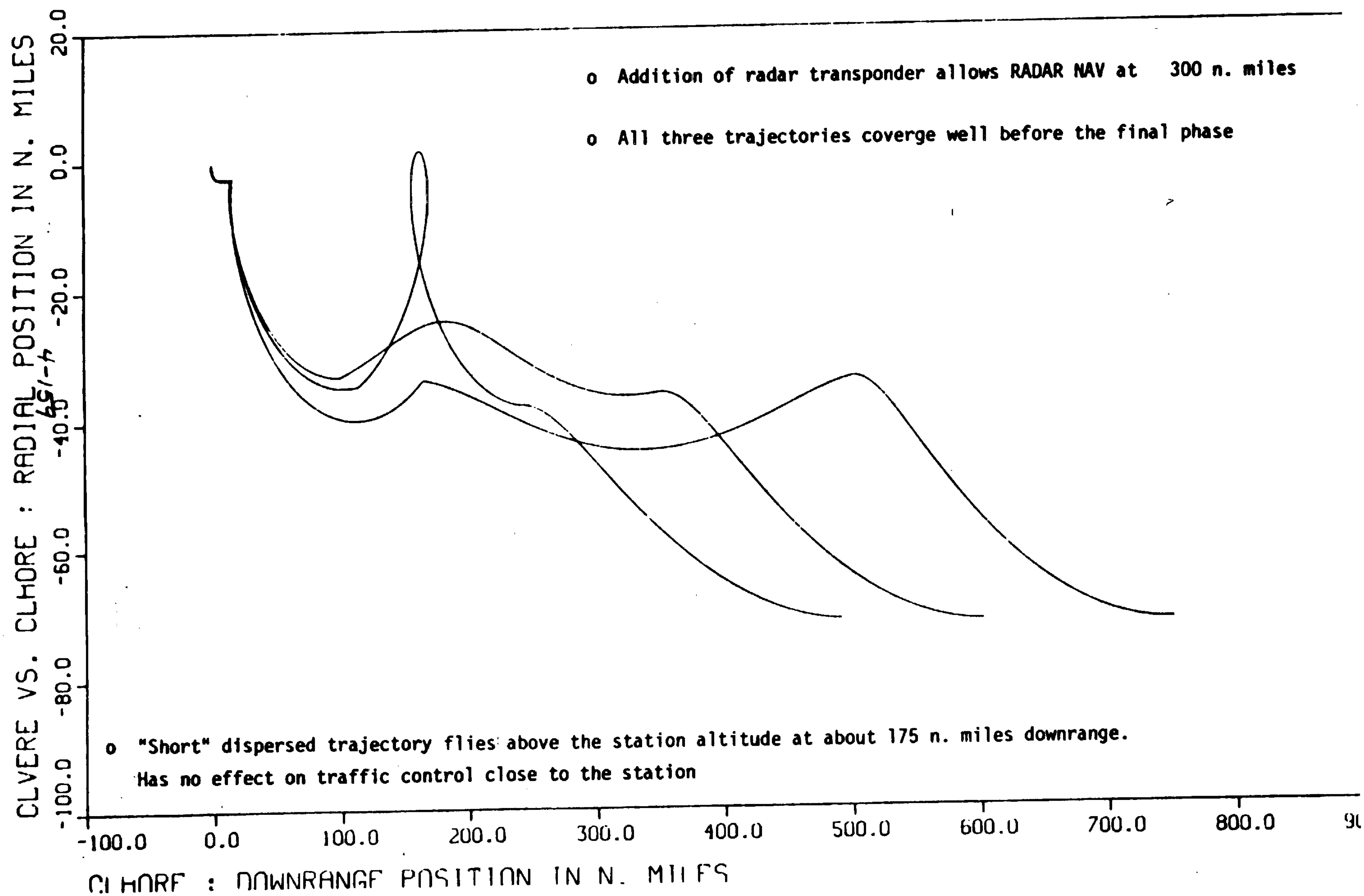
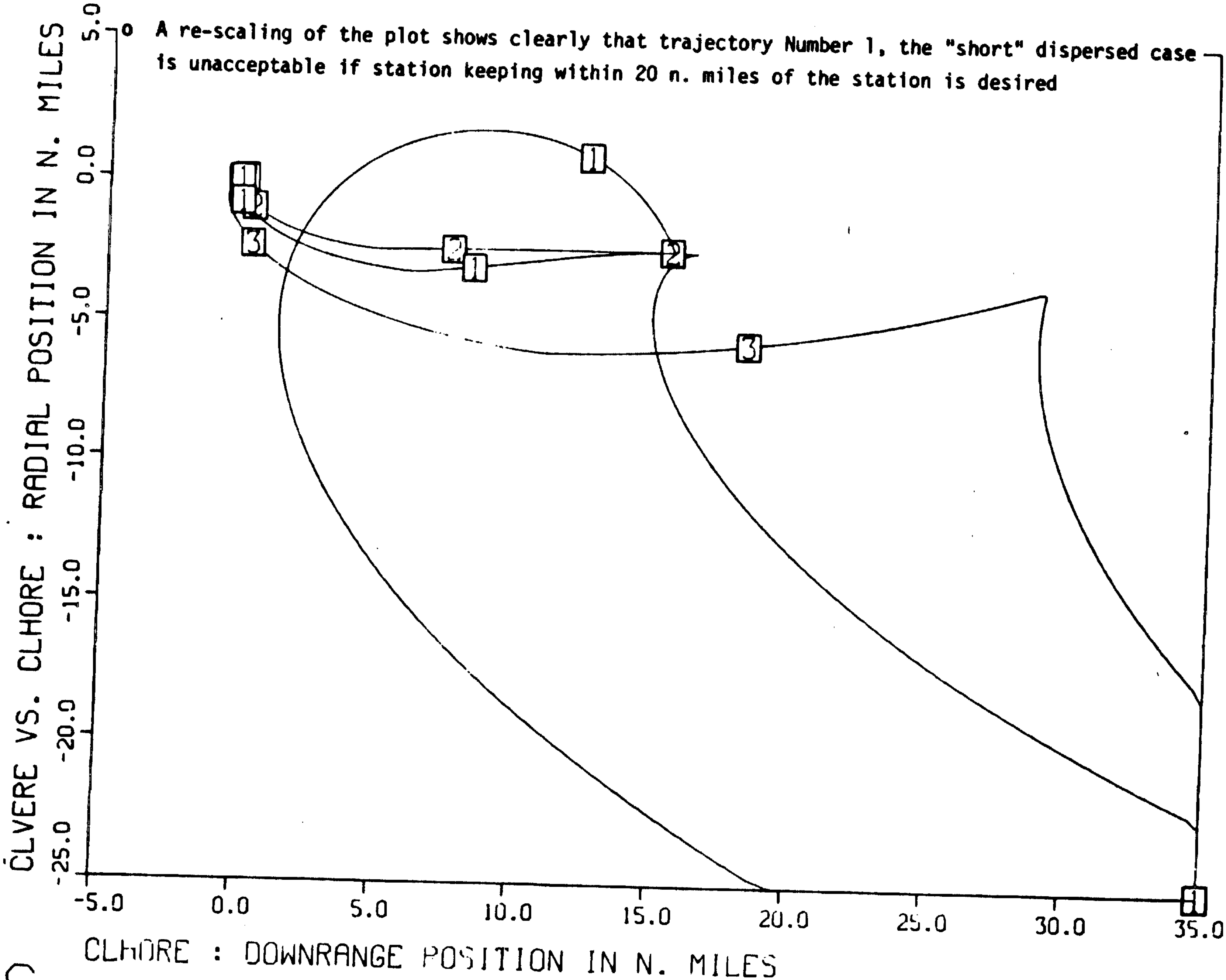
- The most highly dispersed trajectories are plotted, together with a nearly nominal trajectory.
- NOTE that down range dispersion is about 110 n. miles in the "short" case and 135 n. miles in the "long" case" (these are about two sigma).
- The trajectory dispersed short goes up nearly to the station altitude between the 1st and 2nd burns to slow its catchup rate. (The first burn is targeted to reach a point 707,308 feet behind the station in 83.4 minutes).
- Conversely, the trajectory dispersed long lowers its altitude in order to reach the targeted point in a fixed time.
- The second burn occurs at a different point in each case due to NAV errors remaining after star tracking.
- Dispersions are only about 2 miles at the beginning of the coelliptic phase but one trajectory passes very close to the station, and 7 of 60 fly above the "V-bar".
- This behavior <u>may</u> be eliminated by trajectory or NAV tuning.

RR TRANSPONDER & CURRENT TARGETING



CURRENT NAV & TARGETING

- A re-scaling of the plot shows clearly that trajectory Number 1, the "short" dispersed case is unacceptable if station keeping within 20 n. miles of the station is desired



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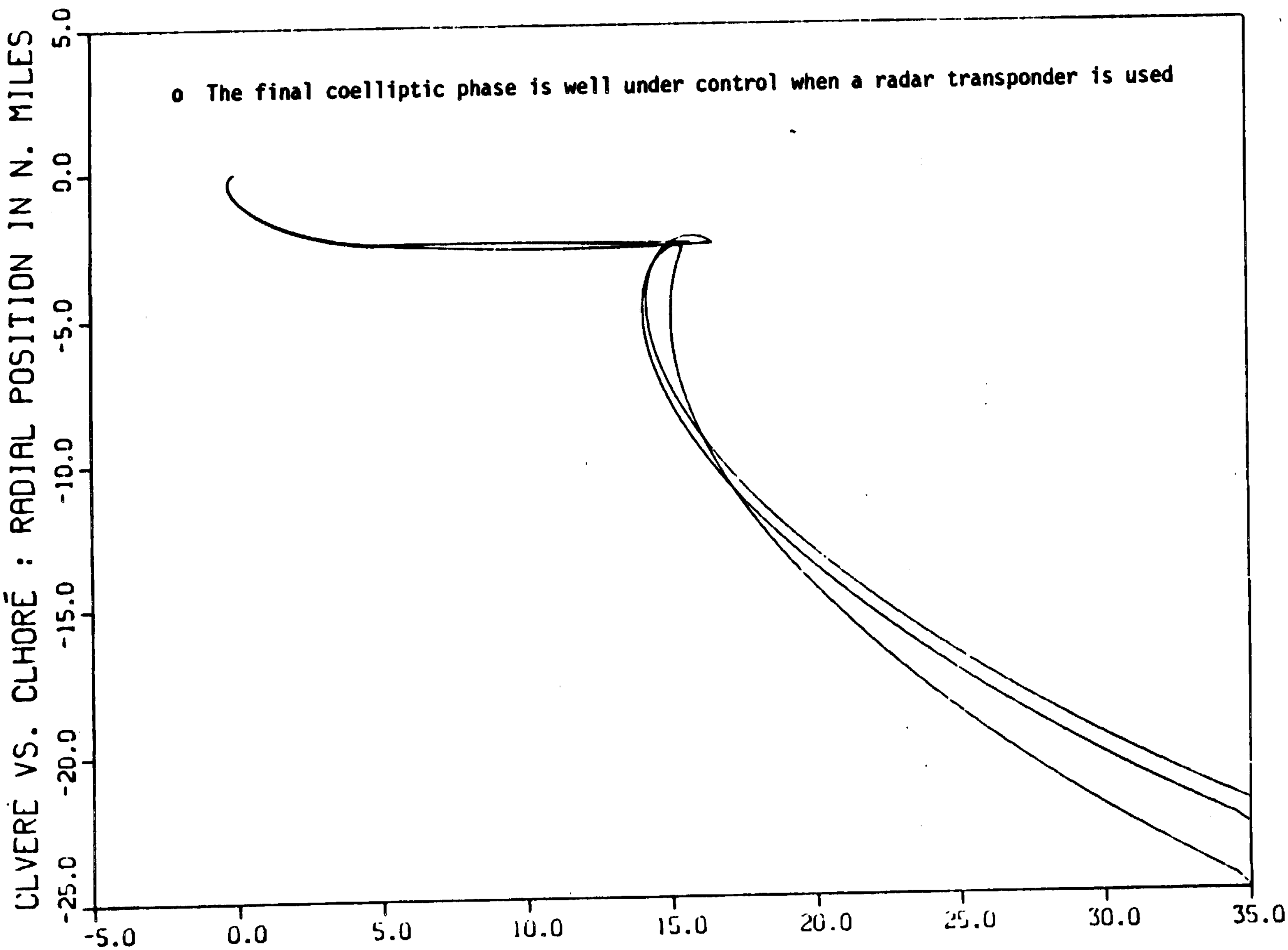
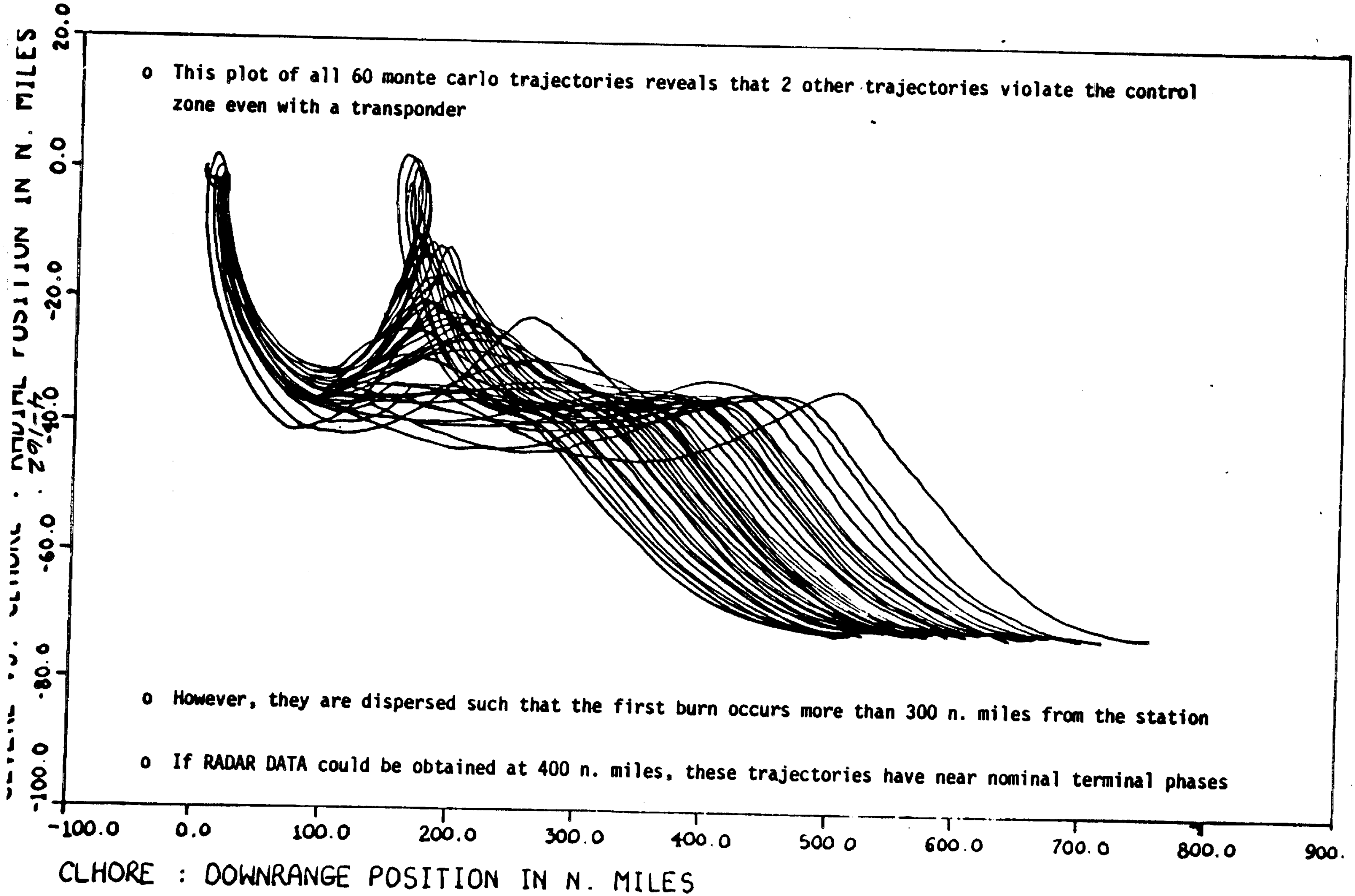
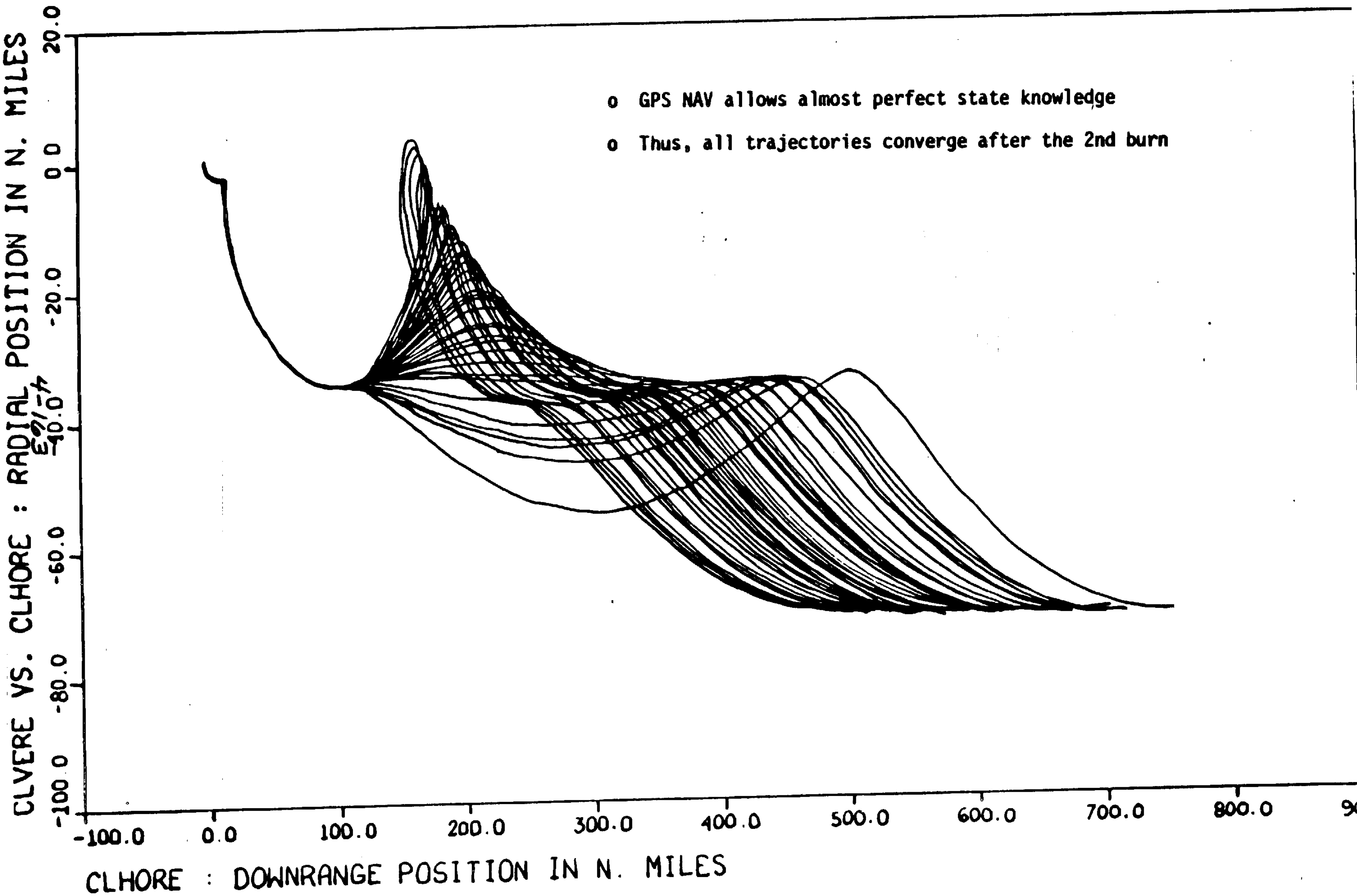
RR TRANSPONDER & CURRENT TARGETING



RR TRANSPONDER & CURRENT TARGETING



GPS NAV & CURRENT TARGETING



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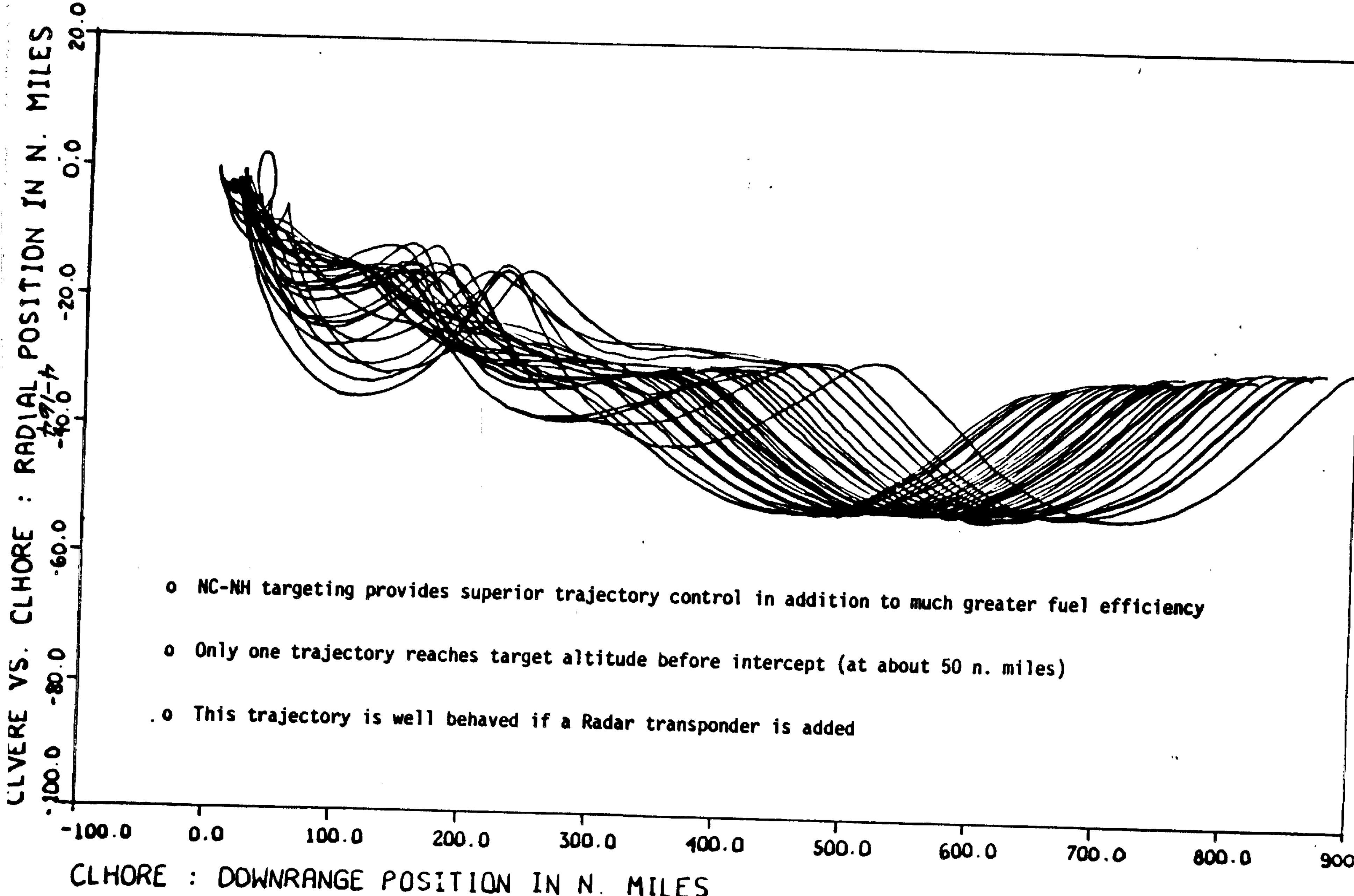
CURRENT NAV & NC-NH TARGETING



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DELTA V SUMMARY (feet per second)

	Current NAV & targeting	RR Transponder & current targeting	GPS NAV & current targeting	Current NAV & NC-NH targeting	RR Transponder & NC-NH targeting
MEAN	218.9	218.1	197.7	201.1	197.8
STD. DEV.	44.2	22.4	15.1	18.7	15.8

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- o NOMINAL DELTA V = 184.0 ft/sec
- o NOTE Dramatic improvement in STD. DEV. with addition of better NAV or targeting
- o The NC-NH profile begins at a higher altitude because the apogee at Meco is greater; thus, less OMS fuel is required.
- o 43.6 ft/sec has been added to the mean for the NC-NH profile to allow a direct comparison with the Lambert profile.
- o Much of the variance in ΔV achieved with RR transponder NAV and NC-NH targeting is due to out of plane maneuver components of the NCC burn

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SUMMARY

- It is feasible for the shuttle to rendezvous with the Space Station using onboard NAV and targeting only if G&N capability is improved; it <u>may</u> be feasible with the current system
- Such a shuttle rendezvous would allow for free-flyer station-keeping close to the Space Station
- Significant reduction in fuel usage and trajectory control are obtained by the addition of better NAV and/or targeting schemes to the current system

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MARS ORBIT AUTOMATED RENDEZVOUS AND DOCKING SYSTEM

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FEBRUARY 20, 1985

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OVERVIEW

- o BACKGROUND
- o MISSION OBJECTIVES
- o RENDEZVOUS SYSTEM ASSUMPTIONS AND CONSTRAINTS
- o THE AUTOMATED GN&C SYSTEM
- o THE SIMULATOR
- o SIMULATION RESULTS
- o CONCLUSIONS

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BACKGROUND

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BACKGROUND

- o EFFORT STARTED IN 1981, UNDER NASA CONTRACT, TO DEFINE AND DEVELOP AUTOMATED RENDEZVOUS, PROXIMITY, AND DOCKING TECHNIQUES
- o THE BASIC PRINCIPLES OF AUTOMATED RENDEZVOUS, PROXIMITY, AND DOCKING OPERATIONS WERE DEFINED
- o THE CONCEPTUAL DESIGN OF AN INTEGRATED GN&C SYSTEM AND VEHICLE THAT WOULD PERFORM AUTOMATED RENDEZVOUS, PROXIMITY, AND DOCKING OPERATIONS WAS FORMULATED
- o THE DESIGN WAS INITIALLY IMPLEMENTED AND VALIDATED ON THE ORBITAL OPERATIONS SIMULATOR (OOS) UTILIZING THE ORBITAL MANEUVERING VEHICLE (OMV) IN THE EARTH ORBIT ENVIRONMENT
- o THE CONCEPTUAL DESIGN OF AN AUTOMATED RENDEZVOUS, PROXIMITY, AND DOCKING SYSTEM FOR THE MARS SAMPLE RETURN MISSION WAS IMPLEMENTED AND VALIDATED ON THE OOS UTILIZING THE OMV IN THE MARS ORBIT ENVIRONMENT

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MISSION OBJECTIVES

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JPL D-1698

Mars Sample Return Mission

FY 84 Study Report to OSSA

26 July 1984

R. D. Bourke
D. Blanchard
J. P. DeVries

JSC JPL

MARS SAMPLE RETURN MISSION
SAMPLE RETURN GOAL

TO RETURN AN INTELLIGENTLY SELECTED SUITE OF MARTIAN MATERIALS FOR DETAILED STUDY IN TERRESTRIAL LABORATORIES.

"THE RETURN OF MARTIAN SURFACE SAMPLES TO EARTH LABORATORIES (UNSTERILIZED) WILL ALLOW THE FULL RANGE OF THE MOST SOPHISTICATED ANALYTICAL TECHNIQUES TO BE APPLIED FOR THE STUDY OF CHRONOLOGY, ELEMENTAL AND ISOTOPIC CHEMISTRY, MINERALOGY AND PETROLOGY AND FOR THE SEARCH FOR CURRENT AND FOSSIL LIFE."

COMPLEX REPORT

MARS SAMPLE RETURN MISSION

PURPOSE OF FY 84 MSR STUDY

- RECOMMEND MISSION OPTION FOR FURTHER STUDY

  MISSION OPTIONS:

  OUT-OF-ORBIT ENTRY VS. DIRECT ENTRY
  MARS ORBIT RENDEZVOUS VS. DIRECT RETURN
  AEROCAPTURE/AEROMANEUVER VS. PROPULSIVE/AEROBALLISTIC
  IN-SITU PROPELLANT PRODUCTION AS POSSIBLE ENHANCEMENT

- IDENTIFY TECHNOLOGY DEVELOPMENT NEEDS

JOINT STUDY: JPL-JSC-SAI

JPL	MARS ARRIVAL AND DEPARTURE OPTIONS
	ROVER
	VEHICLE SYSTEMS
JSC	LAUNCH FROM EARTH, ARRIVAL AT EARTH
	SAMPLE SCIENCE, HANDLING CONTAINMENT
	MARS ORBIT RENDEZVOUS AND DOCKING
SAI	HANDBOOK TYPE INFORMATION ON MASS PERFORMANCE
	COST ESTIMATES

JSC JPL

MARS SAMPLE RETURN MISSION
BASELINE MISSION

OUT-OF-ORBIT ENTRY / MARS ORBIT RENDEZVOUS, WITH AEROCAPTURE / AEROMANEUVER AT MARS

RATIONALE:

- RENDEZVOUS FOR MASS PERFORMANCE:
  - PARK DEPARTURE SYSTEM IN ORBIT
- AEROMANEUVER FOR LANDING SITE ACCURACY: 20 KM, POSSIBLY 10 KM[a]
  AND LANDING SITE AVAILABILITY: ENTIRE PLANET[b]
- AEROCAPTURE FOR MASS PERFORMANCE:
  - ORBIT CAPTURE ENERGY IS TAKEN OUT IN ATMOSPHERIC FLIGHT
  - NEARLY INSENSITIVE TO APPROACH VELOCITY
- OUT-OF-ORBIT ENTRY: ORBIT IS REQUIRED FOR RENDEZVOUS
  - FURTHER IMPROVED LANDING SITE ACCURACY
  - OPERATIONAL FLEXIBILITY

(a) 40 KM WITH AEROBALLISTIC ENTRY

(b) NOT ABOVE 45 DEG. NORTH WITH AEROBALLISTIC ENTRY

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MARS SAMPLE RETURN MISSION

MARS ORBIT RENDEZVOUS ASSUMPTIONS

- LAUNCH SITE LOCATED AT 23°N LATITUDE, 48°W LONGITUDE
- WOULD LIKE 1 day PHASE REPEATING ORBIT (SAME INPLANE PHASE ANGLE AT ASCENT STAGE INSERTION EACH DAY)
  - 1 day PHASE REPEATING ORBIT (443 km/239 N. MI.) NOT POSSIBLE BECAUSE ALTITUDE NECESSARY FOR THIS ORBIT IS BELOW MINIMUM ALLOWED ORBIT (500 km/270 N. MI.)
  - 559 km (302 N. MI.) ORBIT FOR ORBITER SELECTED SINCE THIS ALTITUDE RESULTS IN AN INPLANE PHASE REPEATING ORBIT EVERY OTHER DAY
- ASCENT VEHICLE TARGETED FOR (578 km/312 N. MI.) ORBIT
- RENDEZVOUS MANEUVERS PERFORMED AUTONOMOUSLY BY ORBITING VEHICLE
  - ORBITING VEHICLE TARGETS TO A POINT 18.5 km (10 N. MI.) BELOW AND 46.3 km (25 N. MI.) BEHIND

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MARS SAMPLE RETURN MISSION

MARS ORBIT RENDEZVOUS ASSUMPTIONS (Cont'd)

- THE ASCENT VEHICLE IS PASSIVE IN THE RENDEZVOUS
- THE ASCENT VEHICLE PERFORMS TRIM MANEUVERS TO MINIMIZE RELATIVE POSITION ERROS AT INITIATION OF THE RENDEZVOUS SEQUENCE (THEREBY MAXIMIZING THE RELIABILITY OF THE RENDEZVOUS OPPORTUNITY)
- ASCENT PLANE INCLINATION IS CHOSEN SUCH THAT A RETURN TO EARTH ON THE PLANNED DEPARTURE DATE DOES NOT REQUIRE A PLANE CHANGE
- THE ASCENT TRAJECTORY PROFILE IS COMPATIBLE WITH A NEAR MINIMUM WEIGHT ASCENT VEHICLE
- ORBITER PERFORMS MINIMUM-TIME RENDEZVOUS, KEEPING ASCENT VEHICLE AGAINST DARK SKY BACKGROUND FOR SENSOR UTILIZATION

RENDEZVOUS SYSTEM ASSUMPTIONS AND CONSTRAINTS

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RENDEZVOUS SYSTEM ASSUMPTIONS AND CONSTRAINTS

o SENSORS

- LASER RADAR/INFRARED SENSOR FOR RELATIVE NAV

  RELATIVE POSITION
  MAX RANGE 20 NM (R, E, A)
  MIN RANGE 1 FT (R, E, A)
  OPERATIONAL ENVELOPE - 30 DEG ABOVE HORIZON

  RELATIVE ATTITUDE
  MAX RANGE 120 FT
  MIN RANGE 2 FT

- INFRARED DETECTOR FOV NO CLOSER THEN 30 DEG TO HORIZON
- INERTIAL PLATFORM PERFORMANCE SIMILAR TO ORBITER
- STAR TRACKER FOR PLATFORM ALIGNMENTS

o ORBITER VEHICLE

- OMV
- 24, 5 LB HYDRAZINE THRUSTERS
- FULL UP, AUTOMATED GN&C SYSTEM

o ASCENT VEHICLE

- COUPLED ATTITUDE CONTROL
- MAINTAINS CONSTANT LVLH ATTITUDE

o MISSION PLANNING

- ASCENT VEHICLE ASCENDS TO ORBIT AHEAD AND ABOVE ORBITER
- MINIMIZE RENDEZVOUS AND DOCKING TIME
- COMPLETELY AUTOMATIC FROM LIFTOFF TO DOCK
- ONBOARD AUTOMATIC SYSTEM CAPABLE OF ABORT-TO-STANDOFF DURING AUTO OPERATIONS
- CIRCULAR ORBITS

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THE AUTOMATED GN&C SYSTEM

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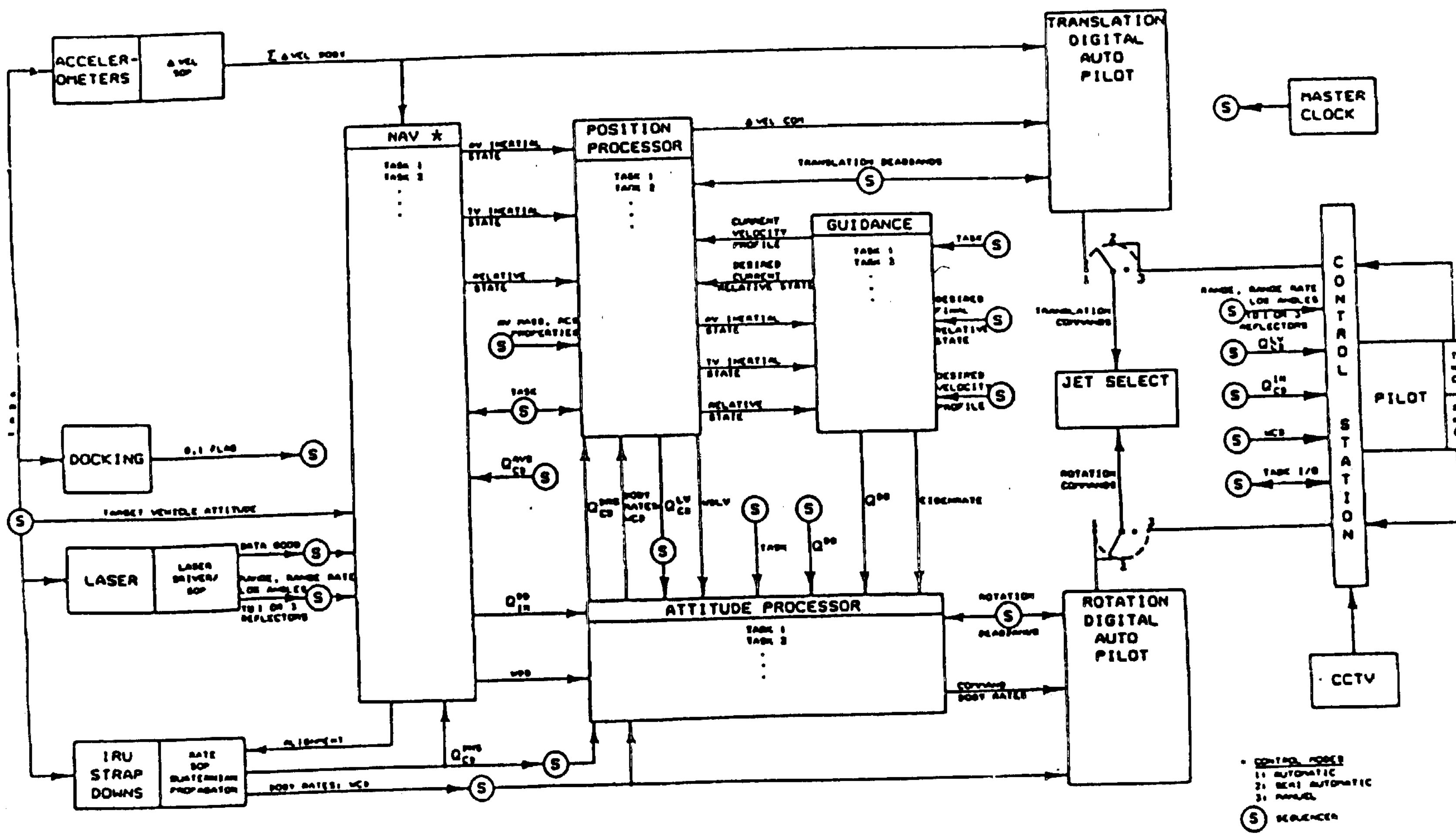
THE AUTOMATED GN&C SYSTEM



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THE SIMULATOR

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EFFECTS MODELED

- o GRAVITY DUE TO SPHERICAL MARS WITH J2, J3, AND J4 NON-SPHERICAL TERMS
- o GRAVITY GRADIENT, AERODYNAMIC AND CONTROL SYSTEM TORQUES
- o AERO DRAG AS A FUNCTION OF ALTITUDE
- o DYNAMIC MASS PROPERTIES CHANGES AS A FUNCTION OF PROPELLANT
- o AUTOMATED CONTROL VIA ONBOARD COMPUTER/SOFTWARE
- o INDIVIDUAL THRUSTER MODELS
- o CCTV DOWNLINK
- o GROUND CONTROL STATION OPERATION
- o INERTIAL AND NAVIGATION SENSORS

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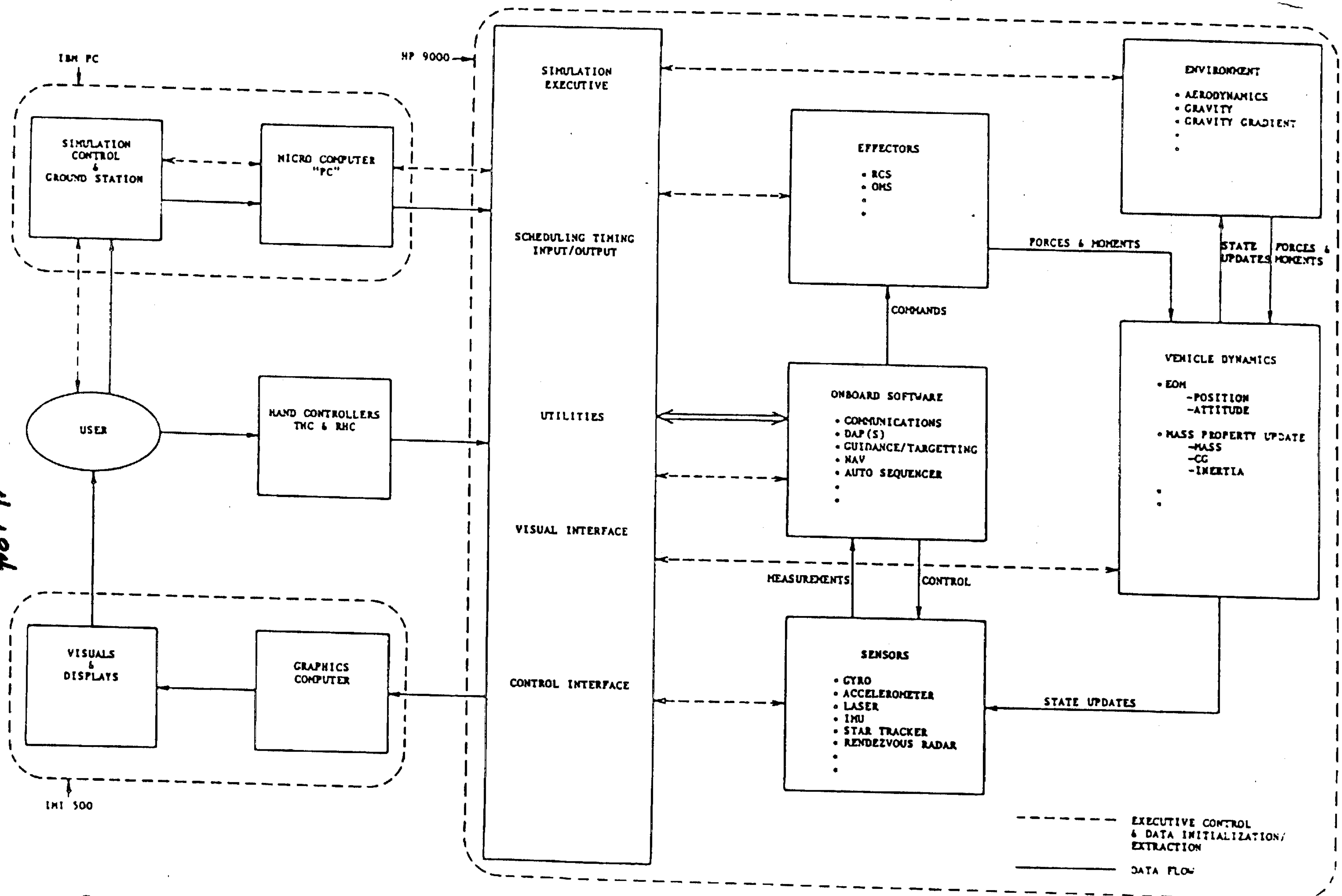

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SIMULATION CONFIGURATION

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RESULTS

o MANEUVER SEQUENCE
o X-Y PLOTS
o 3D GRAPHICS (IMI-500 GRAPHICS COMPUTER)

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MANEUVER SEQUENCE

1) ORBITER IN 262 NM CIRCULAR ORBIT AND COASTING
2) ASCENT VEHICLE L/O TO 2Ø NM X 27Ø NM ORBIT IN ORBITER PLANE
3) ASCENT VEHICLE CIRC BURN AT APOGEE (27Ø NM CIRCULAR)
4) AT CIRC BURN C/O, ASCENT VEHICLE IS 2Ø NM AHEAD AND 8 NM ABOVE ORBITER
5) IMMEDIATELY AFTER CIRC BURN C/O, ASCENT VEHICLE MANEUVERS TO POINT DOCKING PORT DOWN ALONG RADIUS VECTOR (OPTICAL CORNER REFLECTORS POINT ALONG -V AND -R) AND ASSUMES COASTING FLIGHT
6) ORBITER SCANS LASER RADAR ALONG PREDICTED LOS TO ASCENT VEHICLE
7) AT SENSOR LOCK AND DATA GOOD, THE ORBITER'S NAV UPDATES "ASCENT VEHICLE STATE" AND PERFORMS TI/TF TARGETING
8) TI/TF TARGETING IS FOLLOWED IMMEDIATELY BY TI IGNITION
9) POWERED FLIGHT GUIDANCE DURING TI TO DESIRED C/O TARGETS
10) CLOSED LOOP TRAJECTORY CONTROL DURING COAST TO TF IGNITION
11) POWERED FLIGHT GUIDANCE DURING TF TO DESIRED C/O STATE (Ø,Ø,+1ØØØ, AND Ø,Ø,-2)
12) MAINTAIN STRAIGHT LINE APPROACH AT 2 FT/SEC ALONG -R TO 1ØØ FEET
13) STATIONKEEP AT 1ØØ FEET UNTIL DOCKING SENSOR LOCKON AND ASCENT VEHICLE ATTITUDE DATA GOOD FLAG RECEIVED
14) DECREASE POSITION DEADBANDS TO ± 6 INCHES, BEGIN DOCKING APPROACH WITH CLOSING VELOCITY OF 1.5 FT/SEC; REDUCE CLOSING VELOCITY TO ZERO AS RANGE GOES TO ZERO
15) SOFTDOCK
16) ORBITER AND ASCENT VEHICLE CONTROL SYSTEMS OFF
17) HARDDOCK
18) ORBITER CONTROL SYSTEM ON
19) RESUME COASTING FLIGHT

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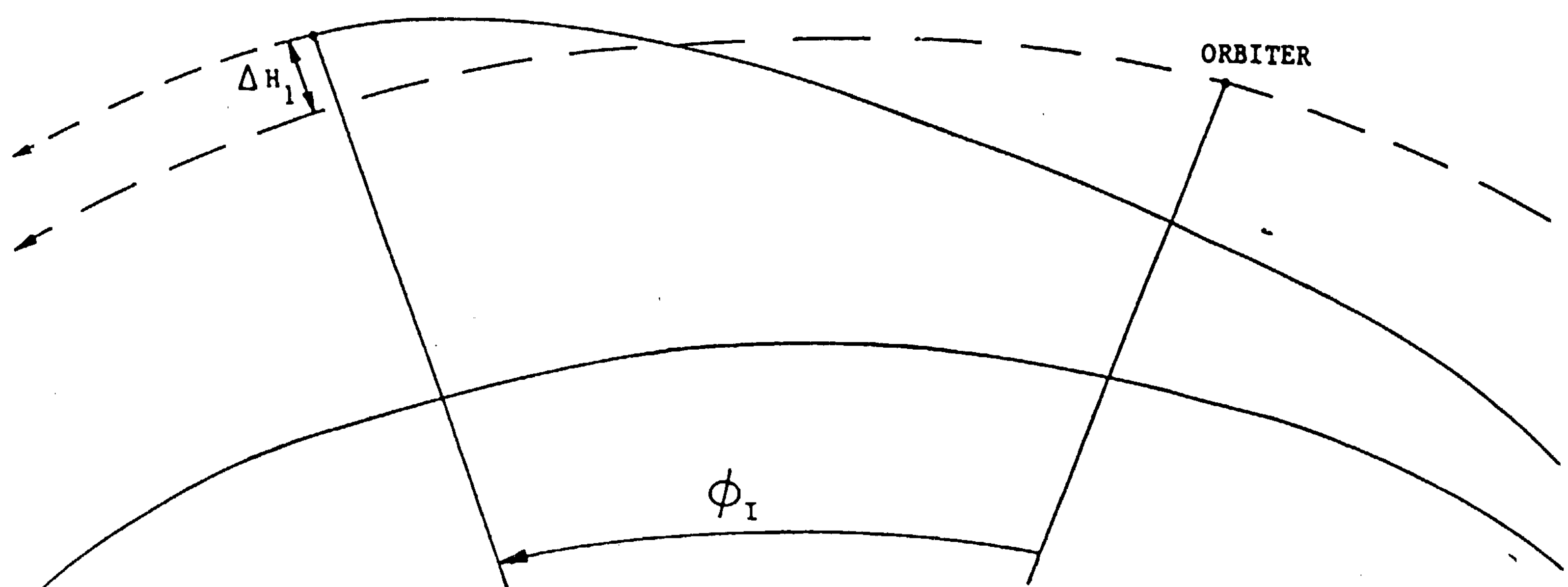
ORBIT INSERTION

- PERIGEE C/O, APOGEE BOOST TO CIRCULARIZE
- IN-PLANE INSERTION
- CIRCULAR ORBITS
- ϕ_I (INITIAL PHASE ANGLE) AND ΔH_1 TO INSURE:
  - •• PHASING
  - •• NAV SENSOR ACQUISITION
  - •• AUTOMATED RENDEZVOUS PHASE INITIAL CONDITIONS



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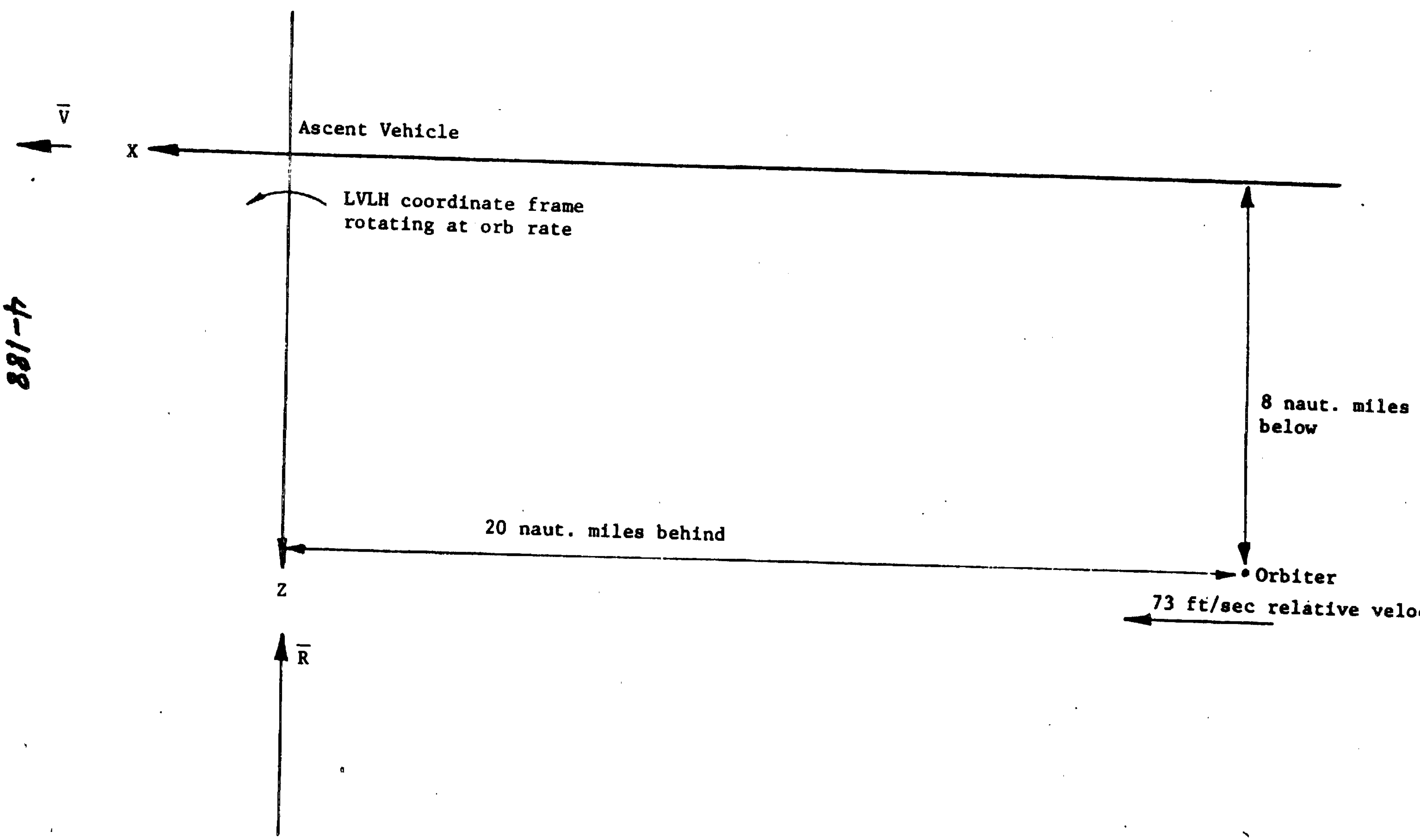
MARS RENDEZVOUS TRAJECTORY

Relative State at Ascent Vehicle's apogee circularization



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X-Y PLOTS

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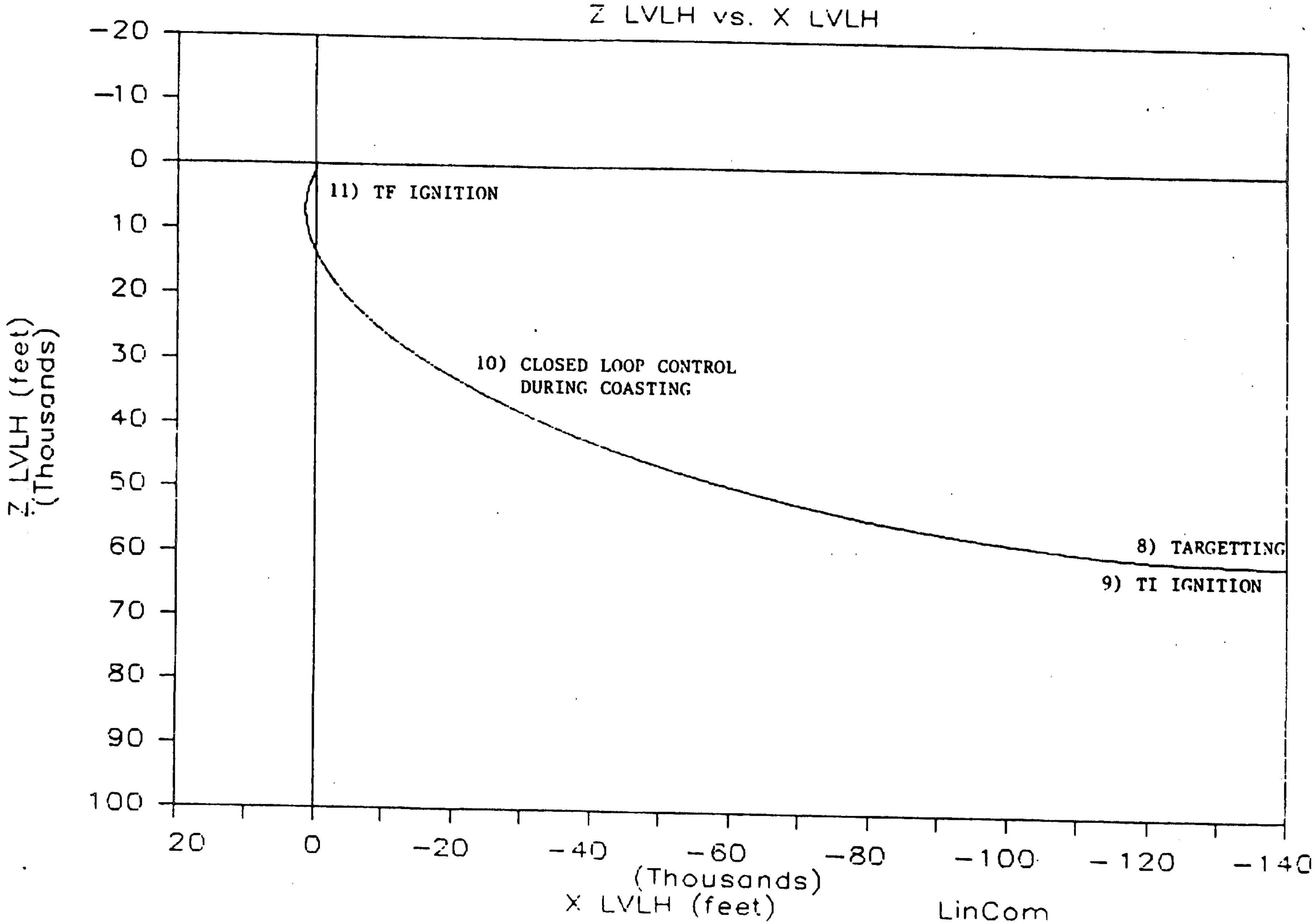
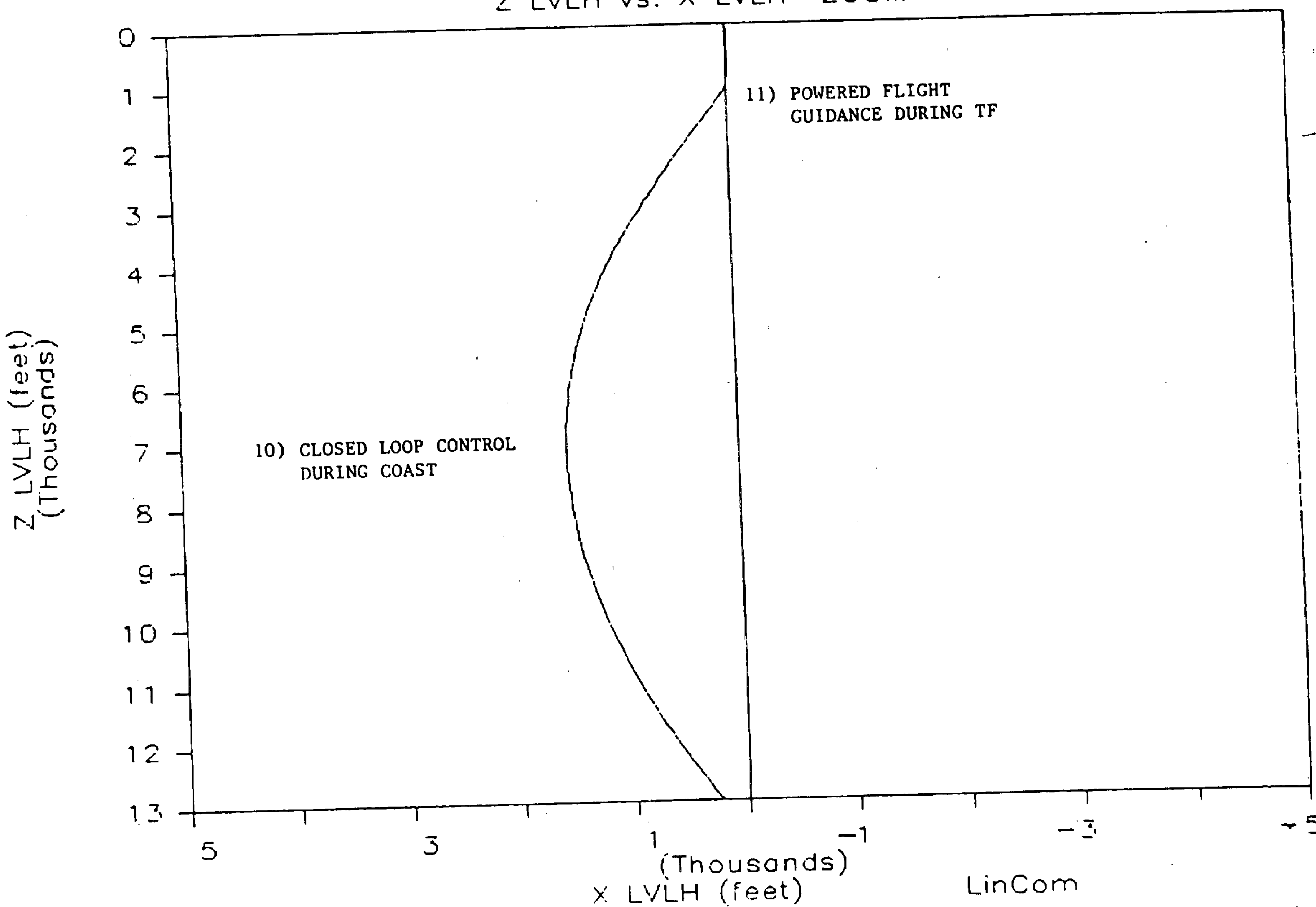
MARS RENDEZVOUS TRAJECTORY

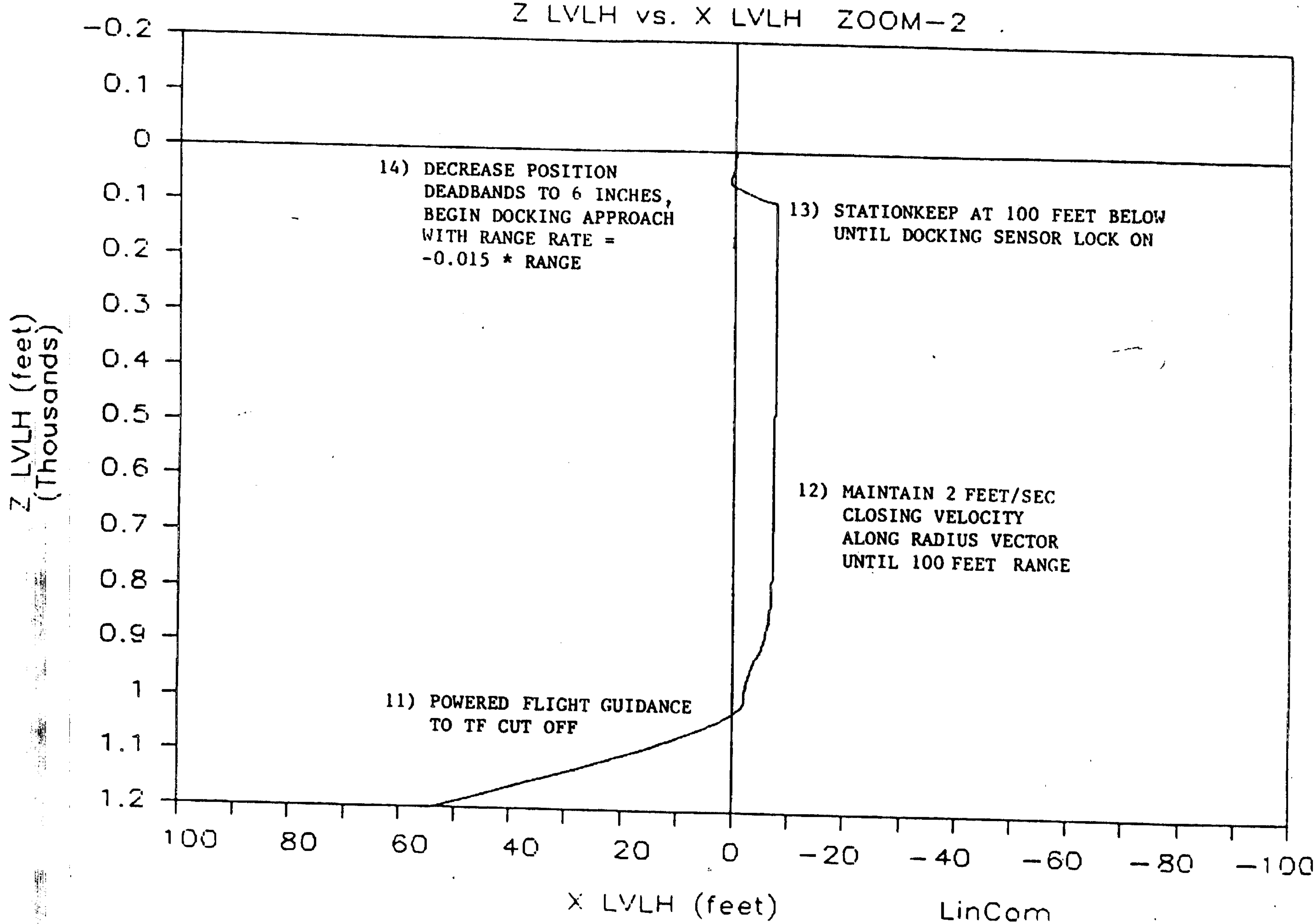


MARS RENDEZVOUS TRAJECTORY

Z LVLH vs. X LVLH ZOOM-1



MARS RENDEZVOUS TRAJECTORY



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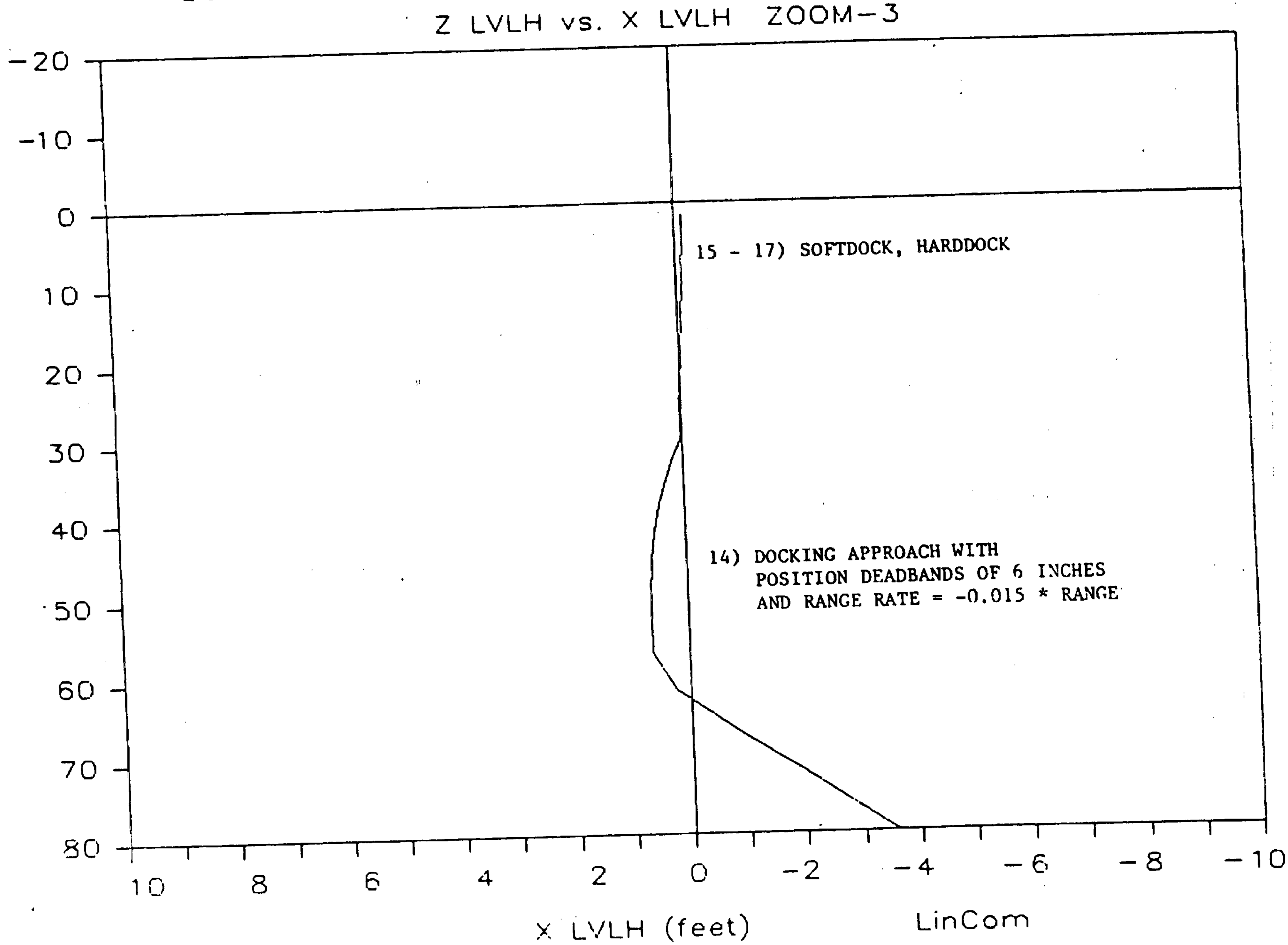
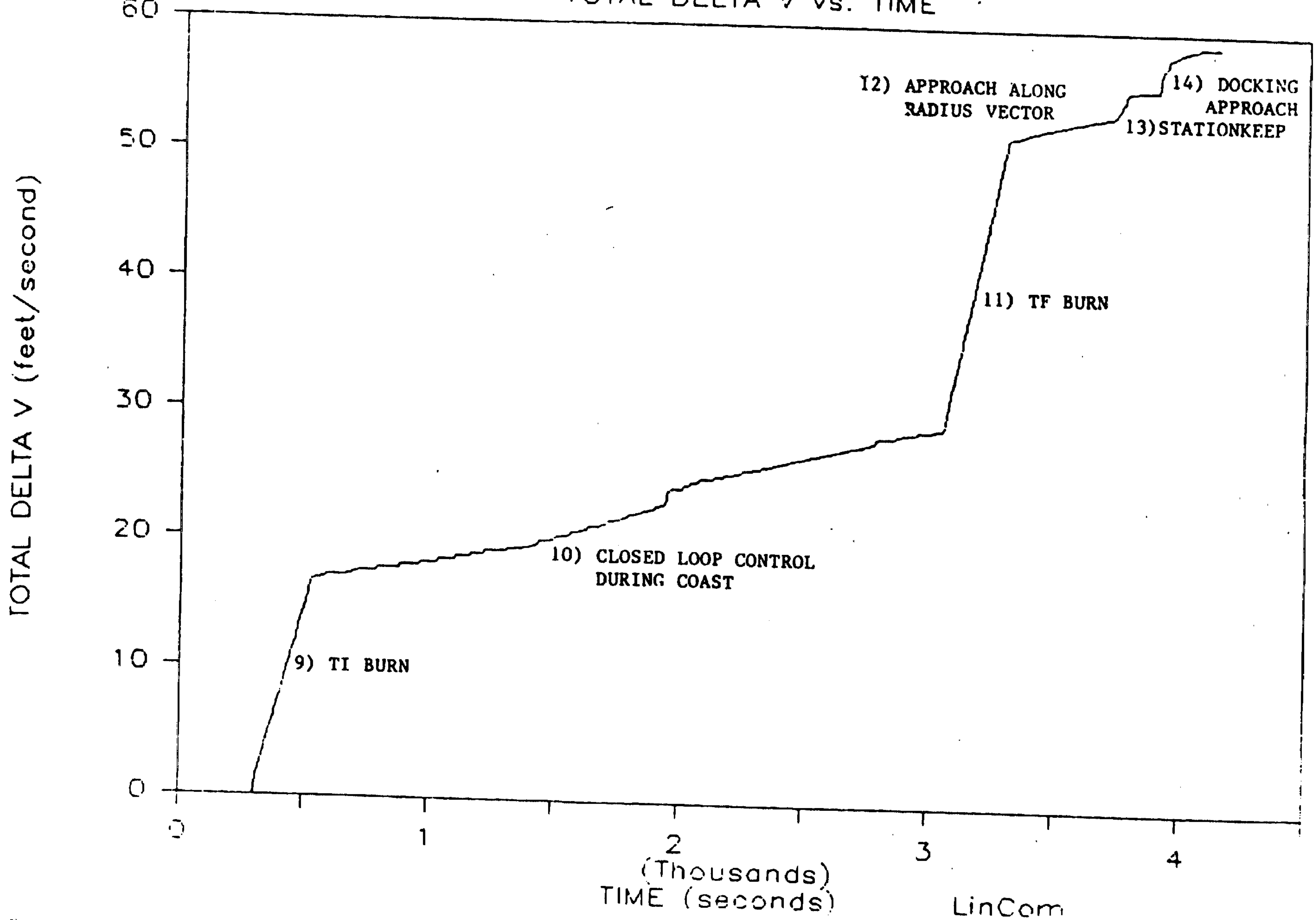
MARS RENDEZVOUS TRAJECTORY



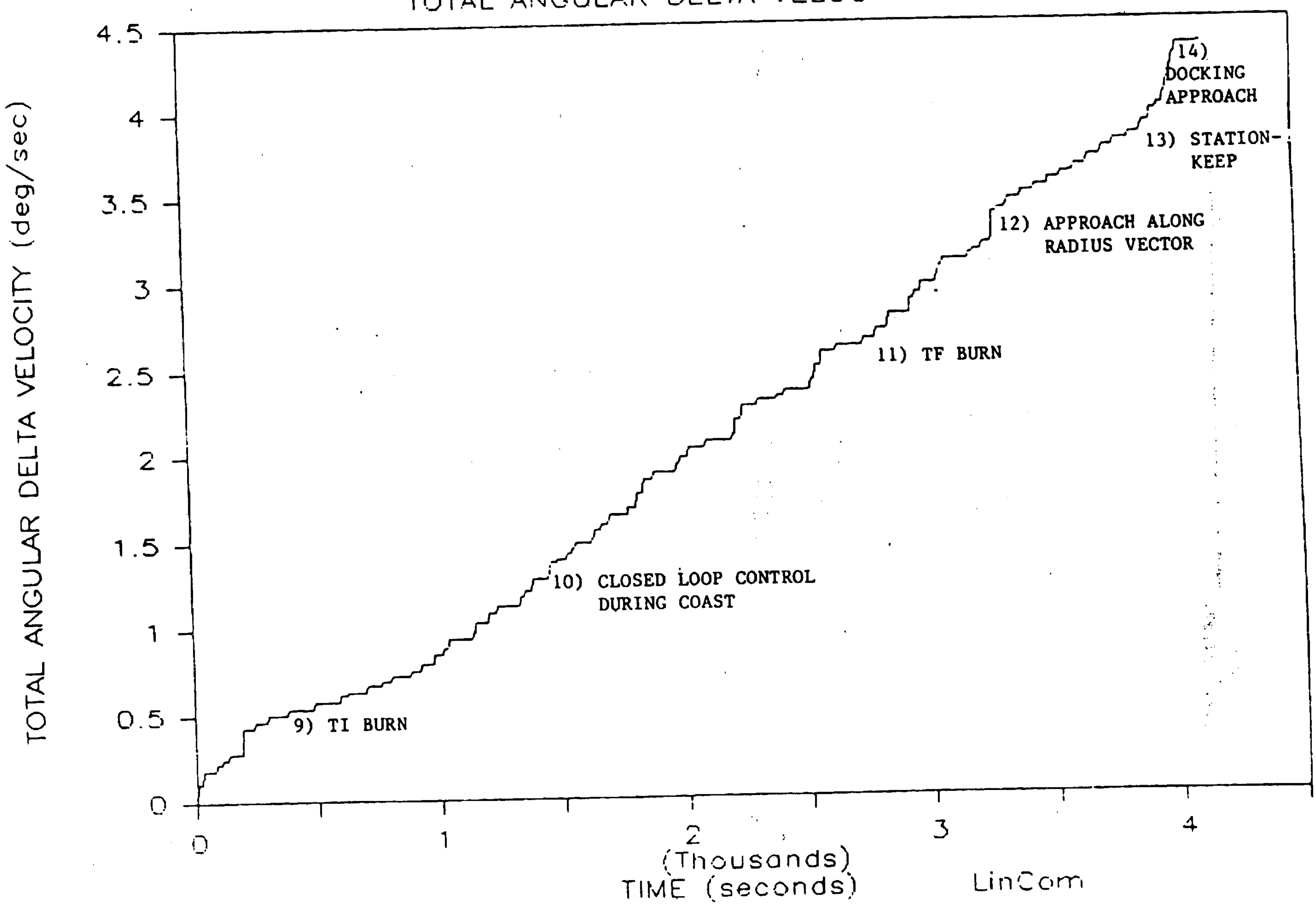
MARS RENDEZVOUS TRAJECTORY

TOTAL DELTA V vs. TIME



MARS RENDEZVOUS TRAJECTORY

TOTAL ANGULAR DELTA VELOCITY vs. TIME



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3D GRAPHICS

(IMI-5ØØ GRAPHICS SYSTEM)

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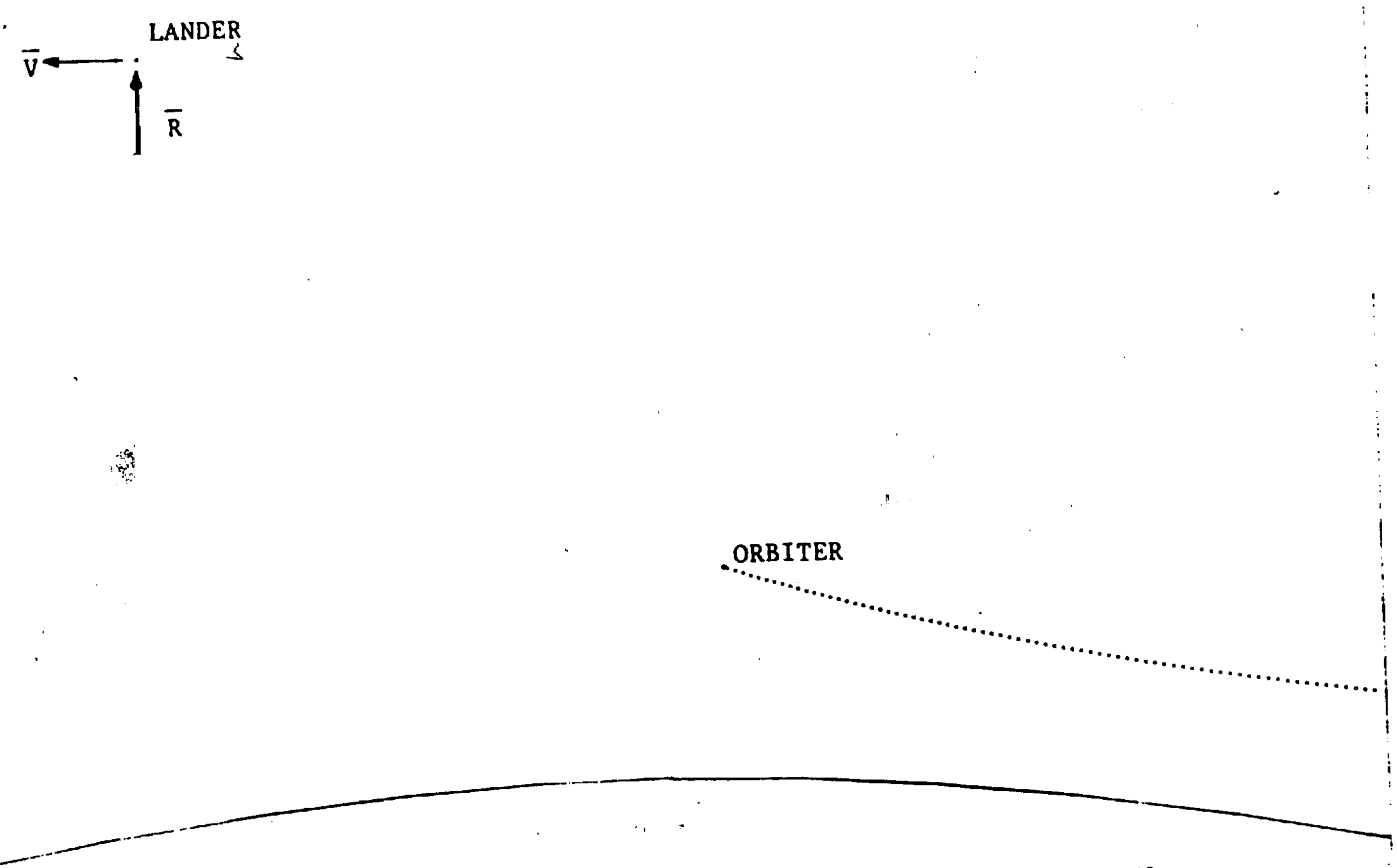
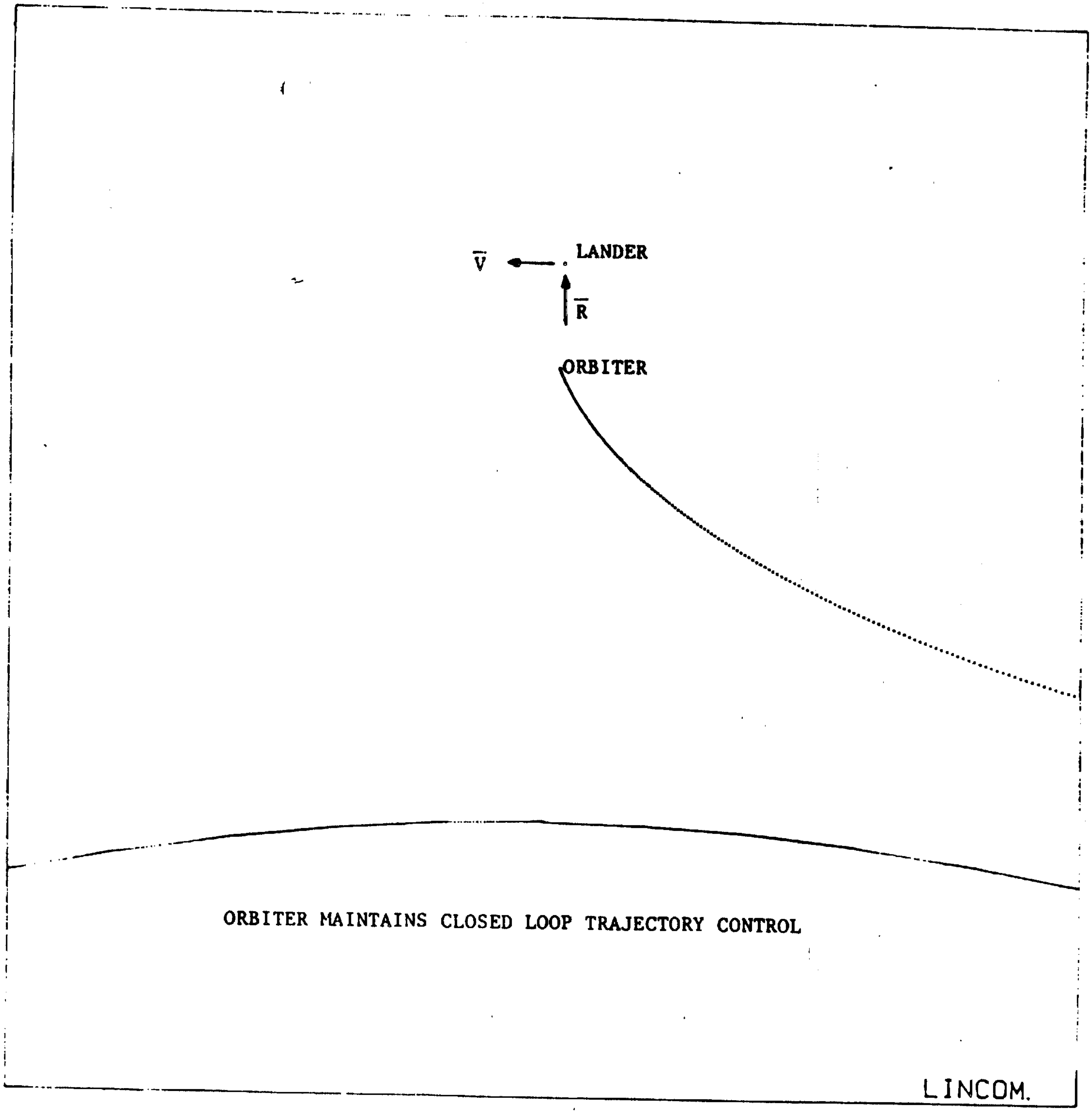


ORBITER PERFORMS CLOSED LOOP TRAJECTORY CONTROL DURING COASTING FLIGHT FROM TRANSITION INITIATION TO TRANSITION FINALIZATION

LINCOM


LANDER
$\bar{V}$
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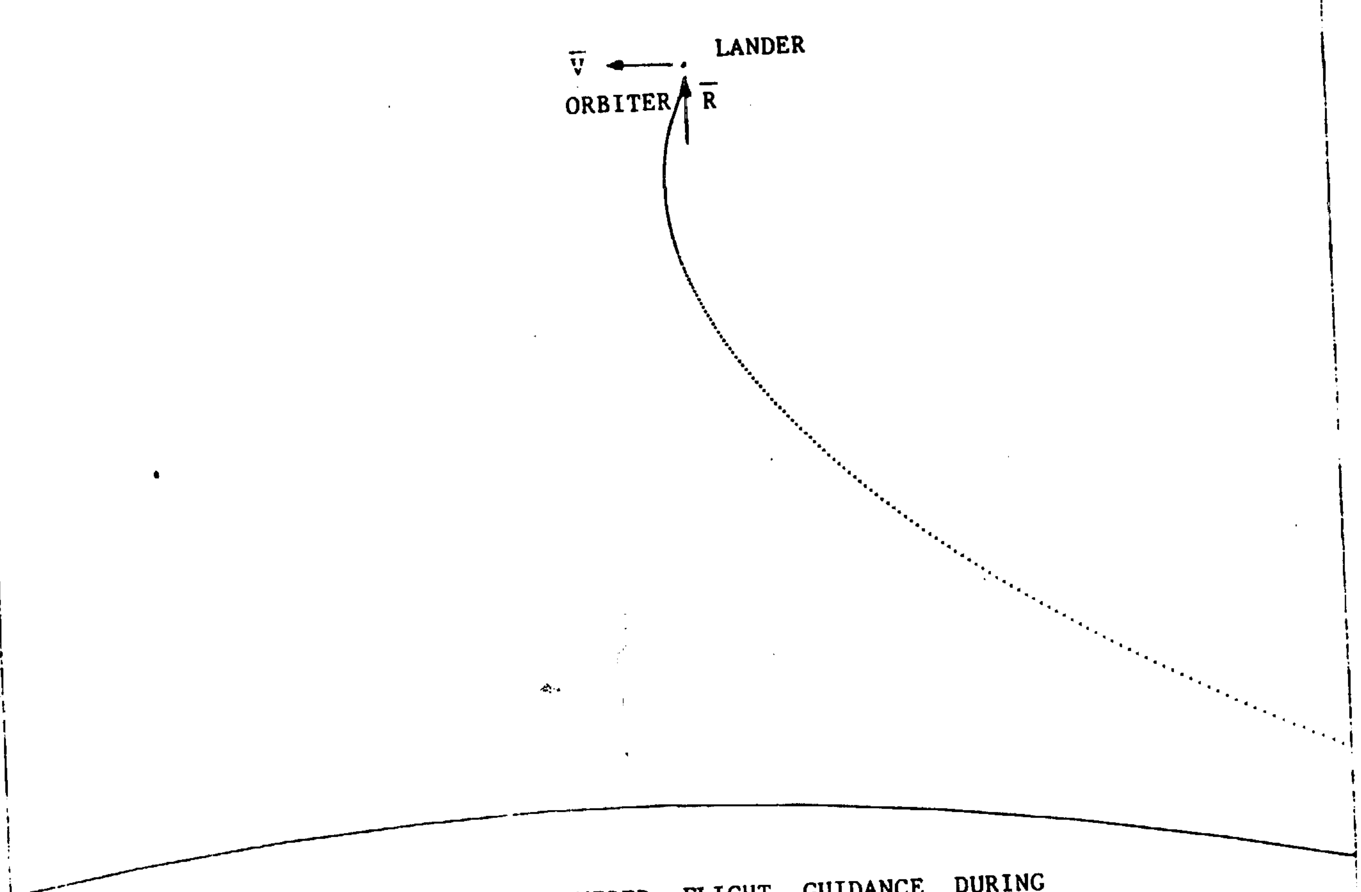
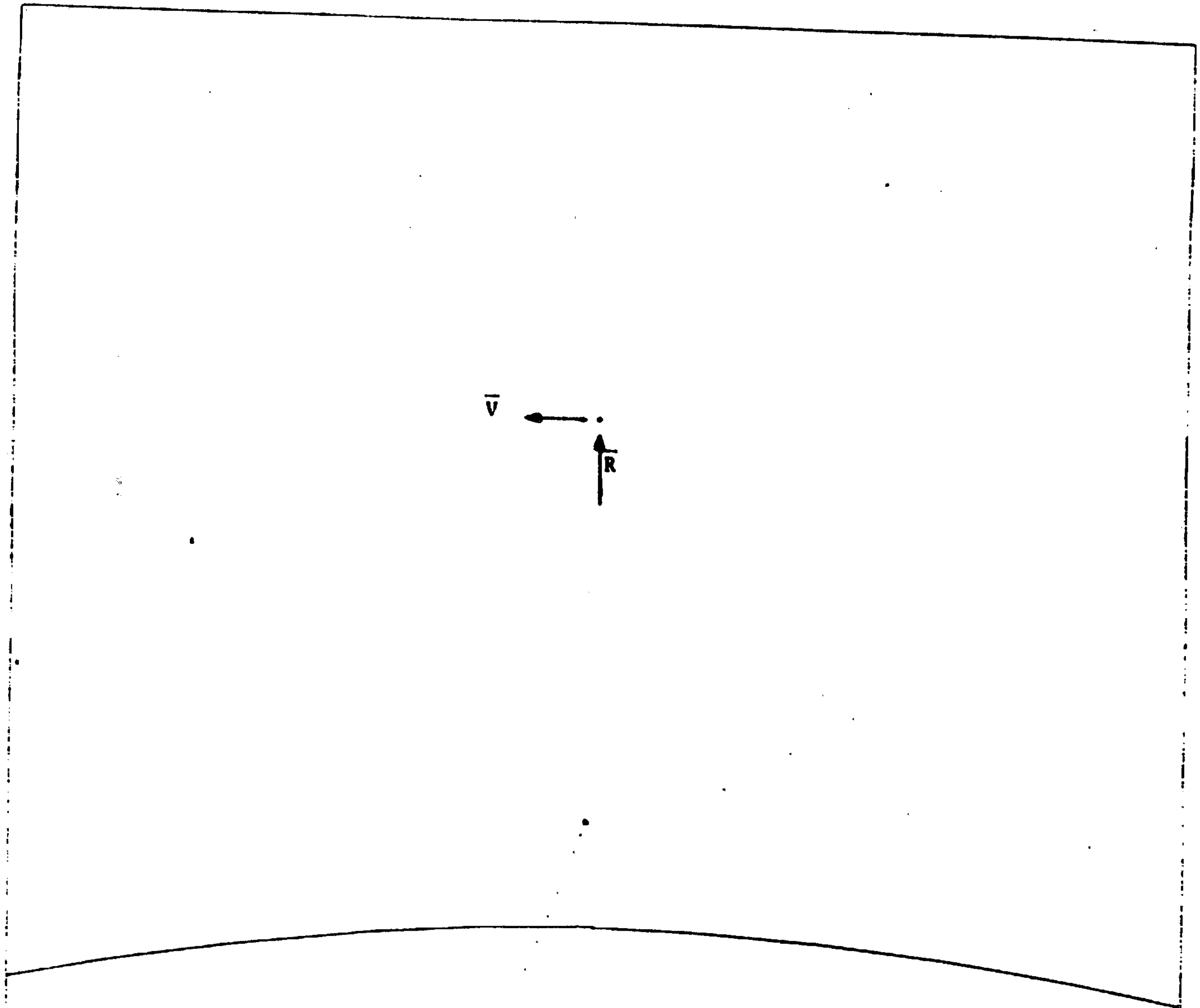
ORBITER
ORBITER MAINTAINS CLOSED LOOP TRAJECTORY CONTROL
LINCOM.



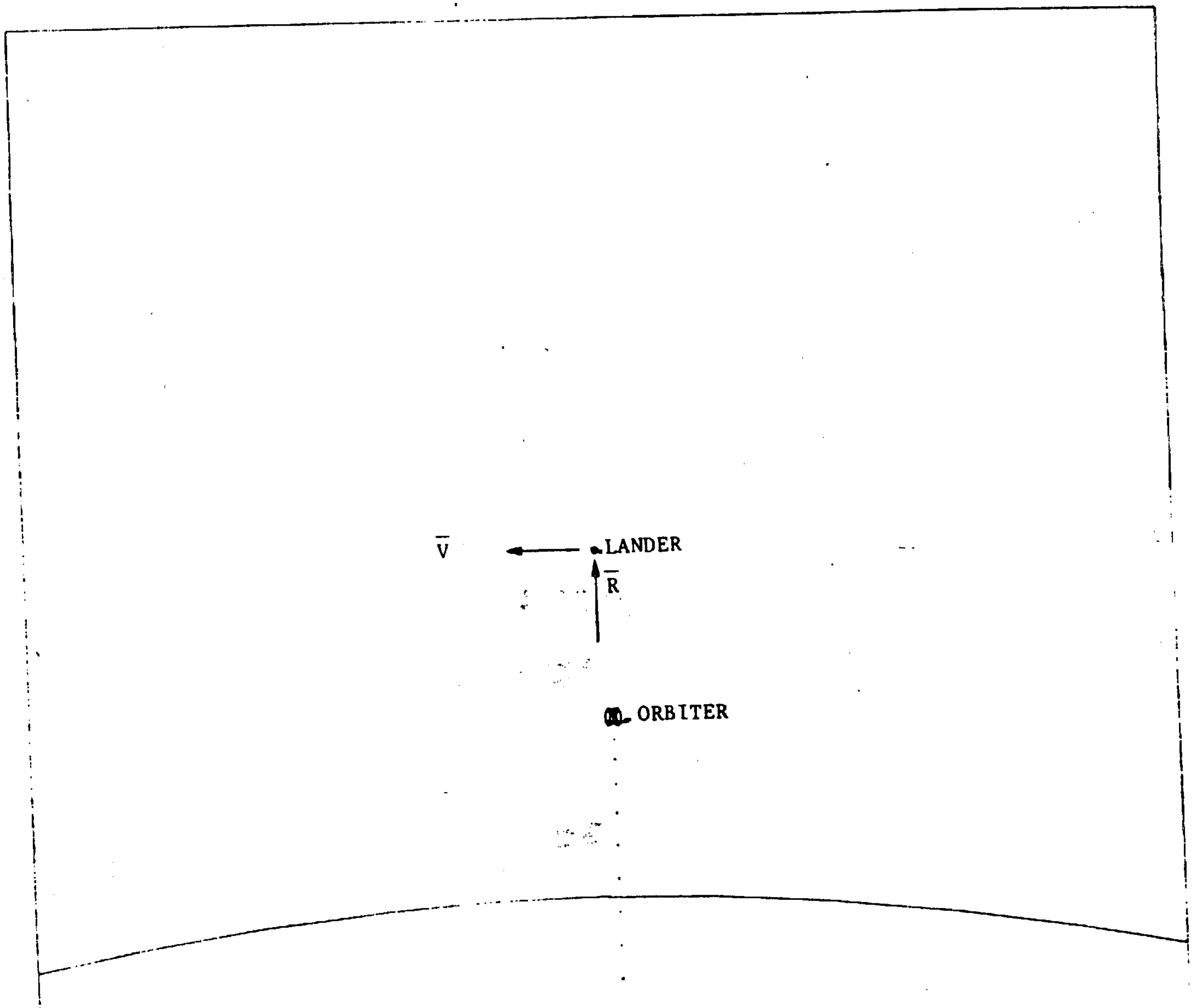
ORBITER PERFORMS POWERED FLIGHT GUIDANCE DURING TRANSITION FINALIZATION TO THE DESIRED THRUSTER CUT OFF STATE (1000 FEET BELOW, CLOSING AT 2 FT/SECOND)

LINCOM.



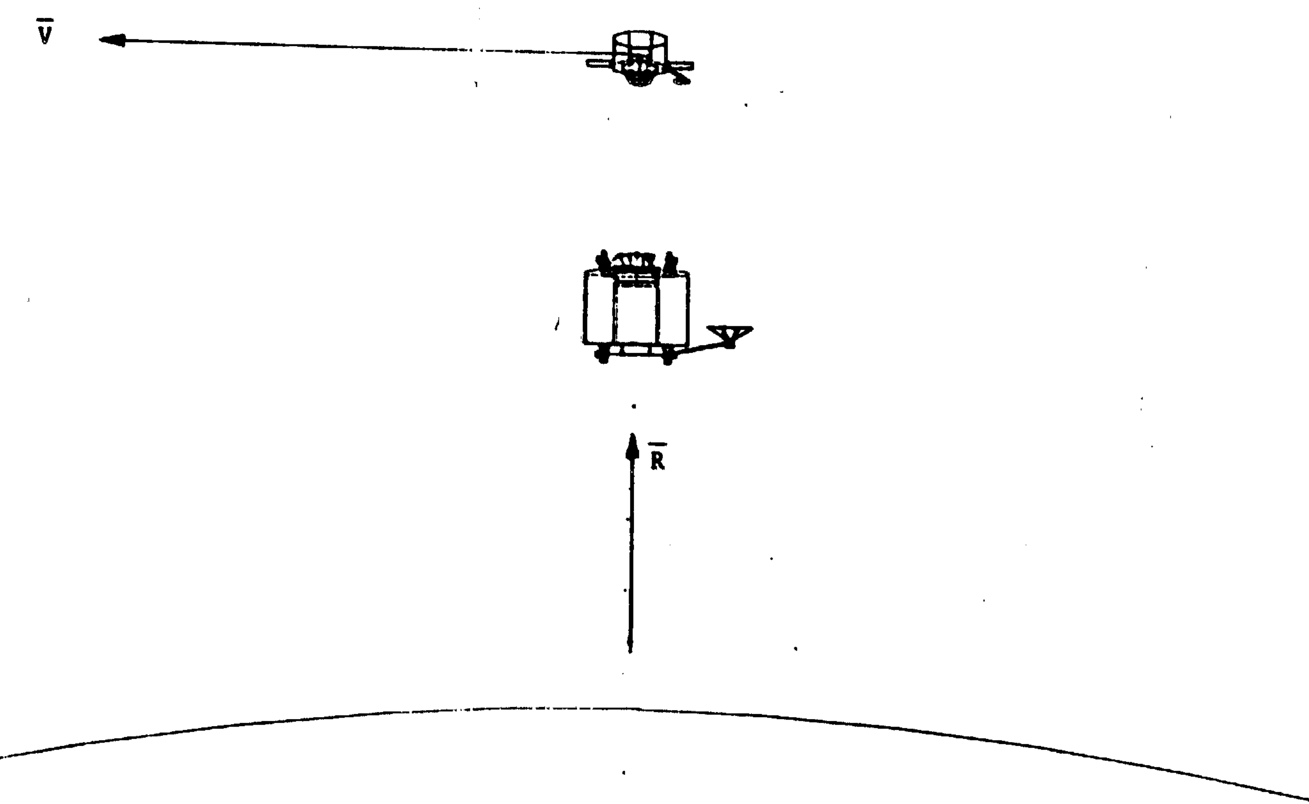
ORBITER MAINTAINS THE 2 FOOT/SECOND
CLOSING RATE ALONG THE RADIUS VECTOR

LINCOM.



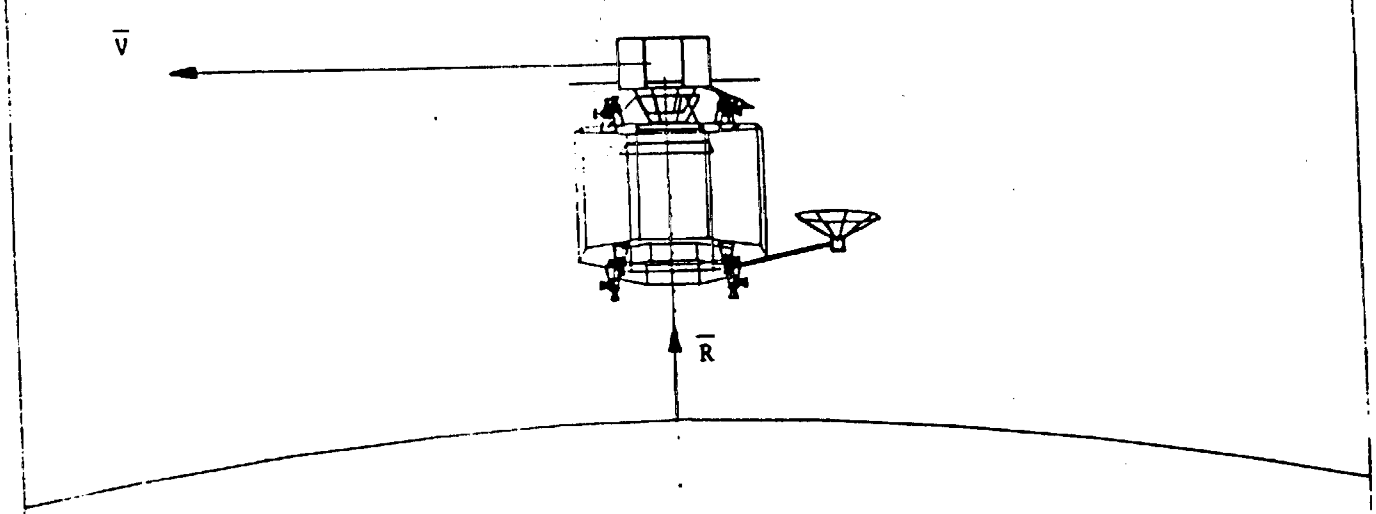
AT A RANGE OF 100 FEET THE ORBITER BRAKES TO STATIONKEEPING, MAINTAINING A 100 FOOT RANGE UNTIL THE DOCKING SENSOR LOCKS ON THE LANDER

LINCOM.



AFTER DOCKING SENSOR LOCK ON THE ORBITER CLOSES ALONG THE DOCKING PORT AXIS, THE CLOSING RANGE RATE IS -0.015 TIMES THE RANGE

LINCOM.



THE ORBITER SOFT-DOCKS WITH THE LANDER, FOLLOWED BY A HARD DOCK

LINCOM.

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CONCLUSIONS

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CONCLUSIONS

- AUTOMATED RENDEZVOUS, PROXIMITY, AND DOCKING TECHNIQUES DEVELOPED OVER THE PAST SEVERAL YEARS FOR EARTH ORBIT SATELLITE SERVICING ARE DIRECTLY APPLICABLE TO MARS ORBIT RENDEZVOUS, PROXIMITY, AND DOCKING OPERATIONS.

- THE RENDEZVOUS AND DOCKING NAVIGATION SENSOR IS CURRENTLY THE "WEAK LINK" IN THE PLAN. THE LASER SENSOR SYSTEM DESCRIBED IN THE SIMULATION HAS NOT YET BEEN DEVELOPED.

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END OF PRESENTATION

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RENDEZVOUS G&N TECHNOLOGY NEEDS

RENDEZVOUS AND PROXIMITY OPERATIONS WORKSHOP

LYNDON B. JOHNSON SPACE CENTER

JPL

Allan Klumpp

1985 FEBRUARY 20

4-207

JPL

RENDEZVOUS G&N TECHNOLOGY NEEDS

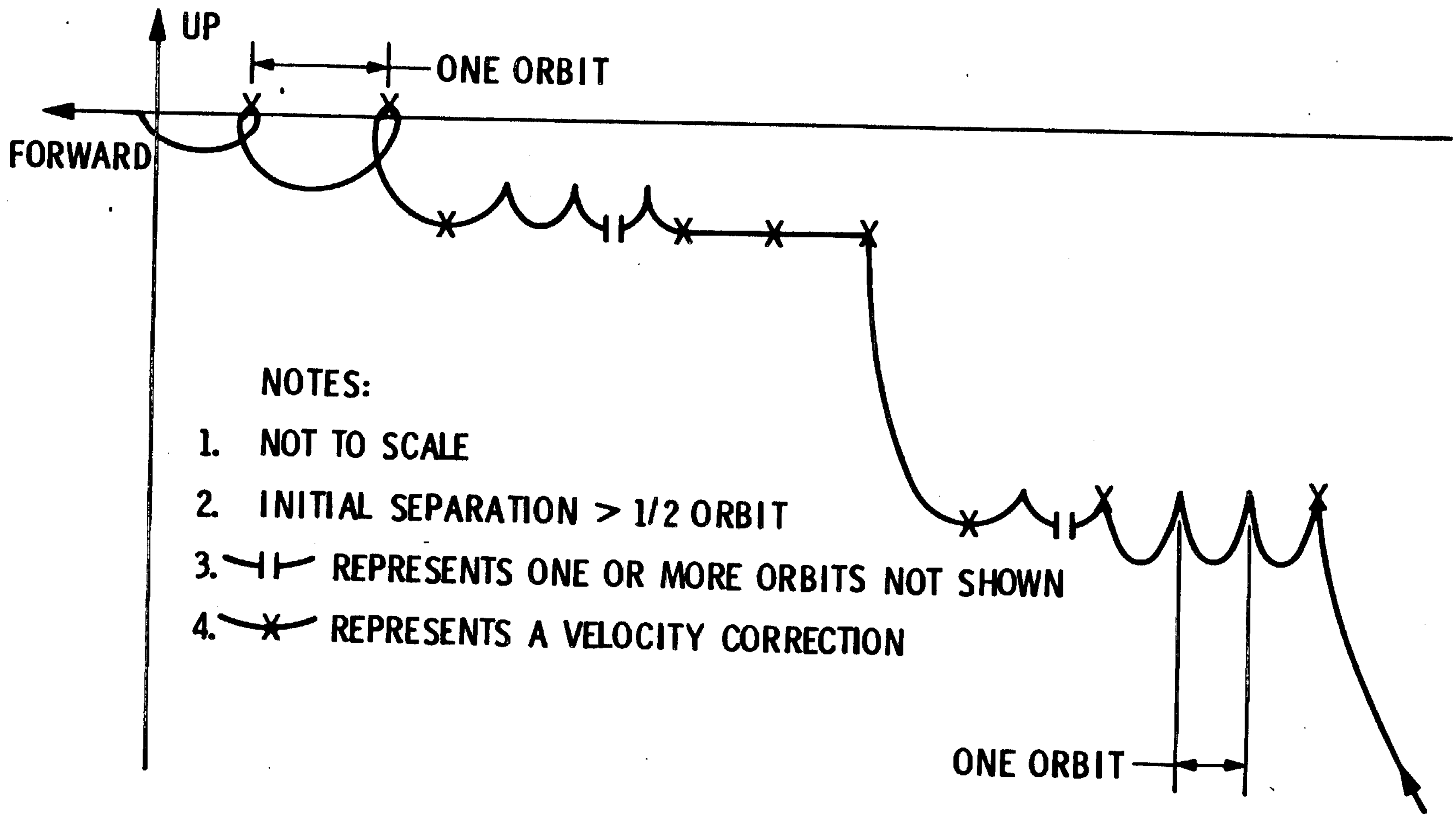
- CURRENT TECHNOLOGY – AN EXAMPLE
- REQUIREMENTS FOR RENDEZVOUS G&N – NEW AND TRADITIONAL
- NEW INGREDIENTS OF RENDEZVOUS G&N
- NEW-TECHNOLOGY RENDEZVOUS EXAMPLE
- A POSSIBLE RENDEZVOUS G&N TECHNOLOGY DEVELOPMENT PROGRAM

JPL

CURRENT TECHNOLOGY

- MULTIPLE DISCRETE TRAJECTORY ARCS
- SEVERAL ORBITS REQUIRED TO RENDEZVOUS
- RENDEZVOUS TIME-CONSUMING, OPERATIONALLY EXPENSIVE

A PLANAR CURRENT-TECHNOLOGY RENDEZVOUS

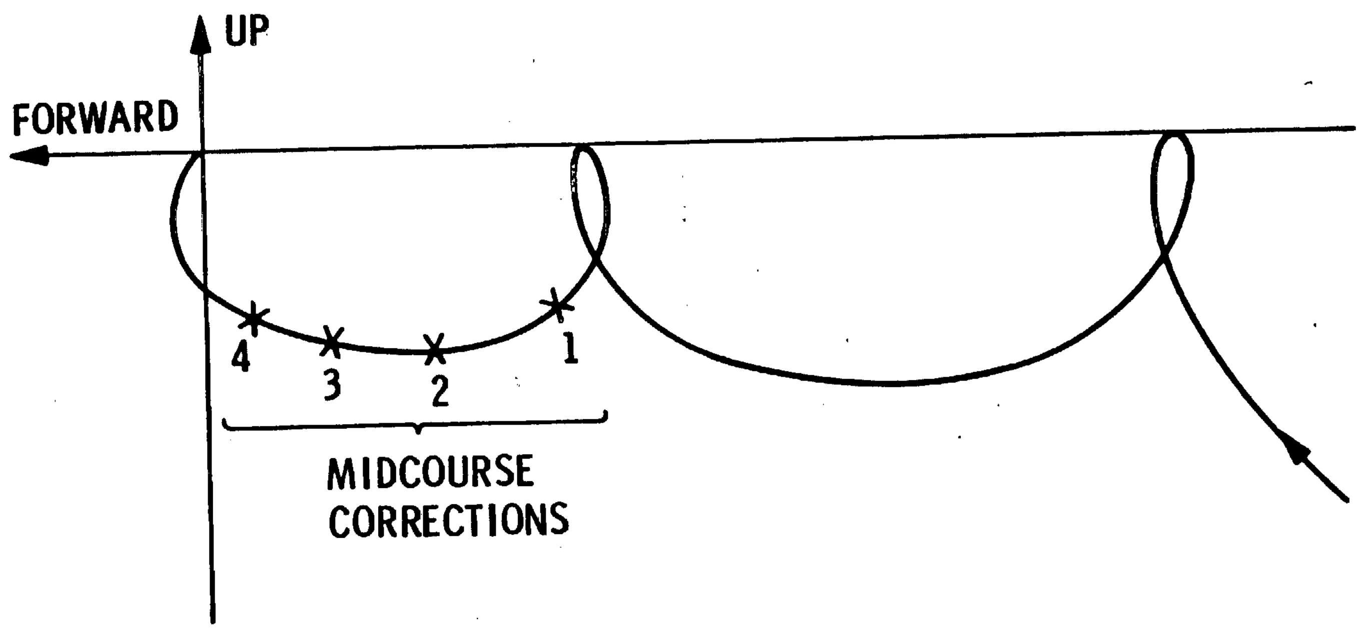


NOTES:

1. NOT TO SCALE
2. INITIAL SEPARATION > 1/2 ORBIT
3. REPRESENTS ONE OR MORE ORBITS NOT SHOWN
4. REPRESENTS A VELOCITY CORRECTION

JPL

A PLANAR CURRENT-TECHNOLOGY RENDEZVOUS
MIDCOURSE PHASE



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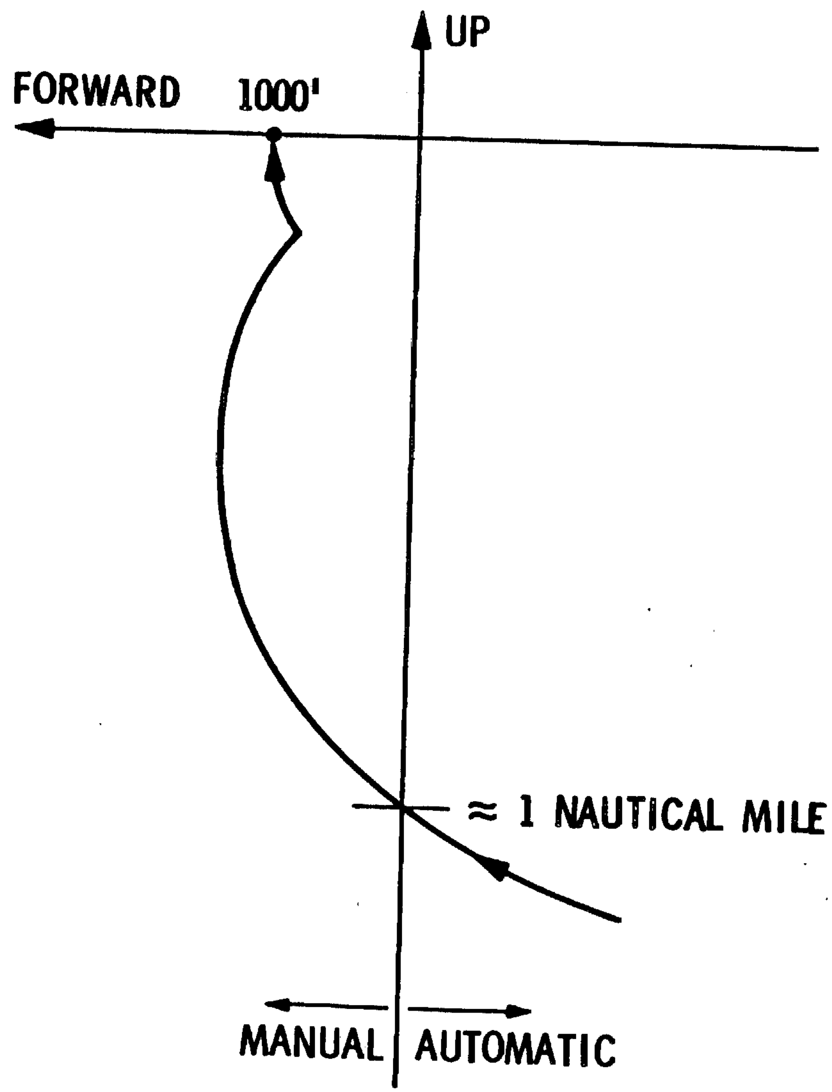
A PLANAR CURRENT-TECHNOLOGY RENDEZVOUS

APPROACH PHASE



JPL NEW REQUIREMENTS FOR RENDEZVOUS G&N

- AUTONOMY – DEMANDS ON FLIGHT AND GROUND CREWS MUST BE GREATLY REDUCED
- CREW PARTICIPATION – MONITORING AND OVERRIDING MUST BE PERMITTED BUT NOT REQUIRED
- TRANSIT TIME – SHORT: A SINGLE-ORBIT MIDCOURSE PHASE FOR GEOMETRY ADJUSTMENT IS HIGHLY DESIRABLE
- WIDE APPLICABILITY:
  - A SINGLE G&N SYSTEM MUST PRODUCE ANY TYPE OF RENDEZVOUS TRAJECTORY
  - A SINGLE G&N SYSTEM MUST SERVE A VARIETY OF RENDEZVOUSING SPACECRAFT

JPL

TRADITIONAL REQUIREMENTS STILL APPLICABLE

- <u>SAFETY</u>:
  - AVOID A COLLISION COURSE UNTIL DOCKING IS IMMINENT - TARGET OFFSET
  - REDUCE APPROACH SPEED GRADUALLY – APPROX CONSTANT RANGE/(RANGE RATE)
- <u>LIGHTING</u> – TO PERMIT CREW PARTICIPATION, LIGHTING IS CONSTRAINED. THEREFORE G&N MUST PROVIDE FIXED TIME OF ARRIVAL
- <u>PROPELLANT CONSUMPTION</u> – MUST BE EFFICIENT, NEED NOT BE OPTIMAL

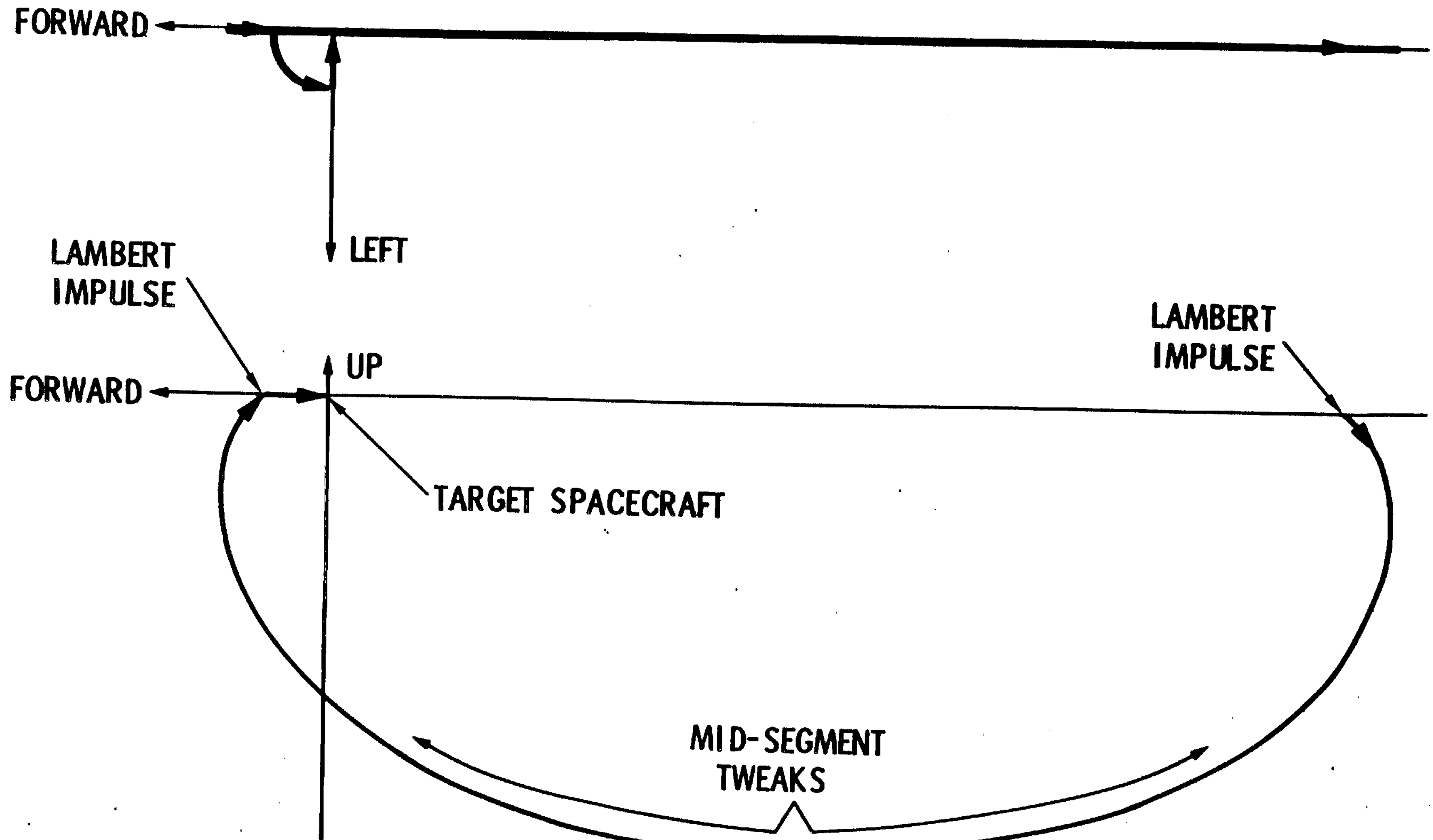
JPL

NEW INGREDIENTS OF RENDEZVOUS G&N

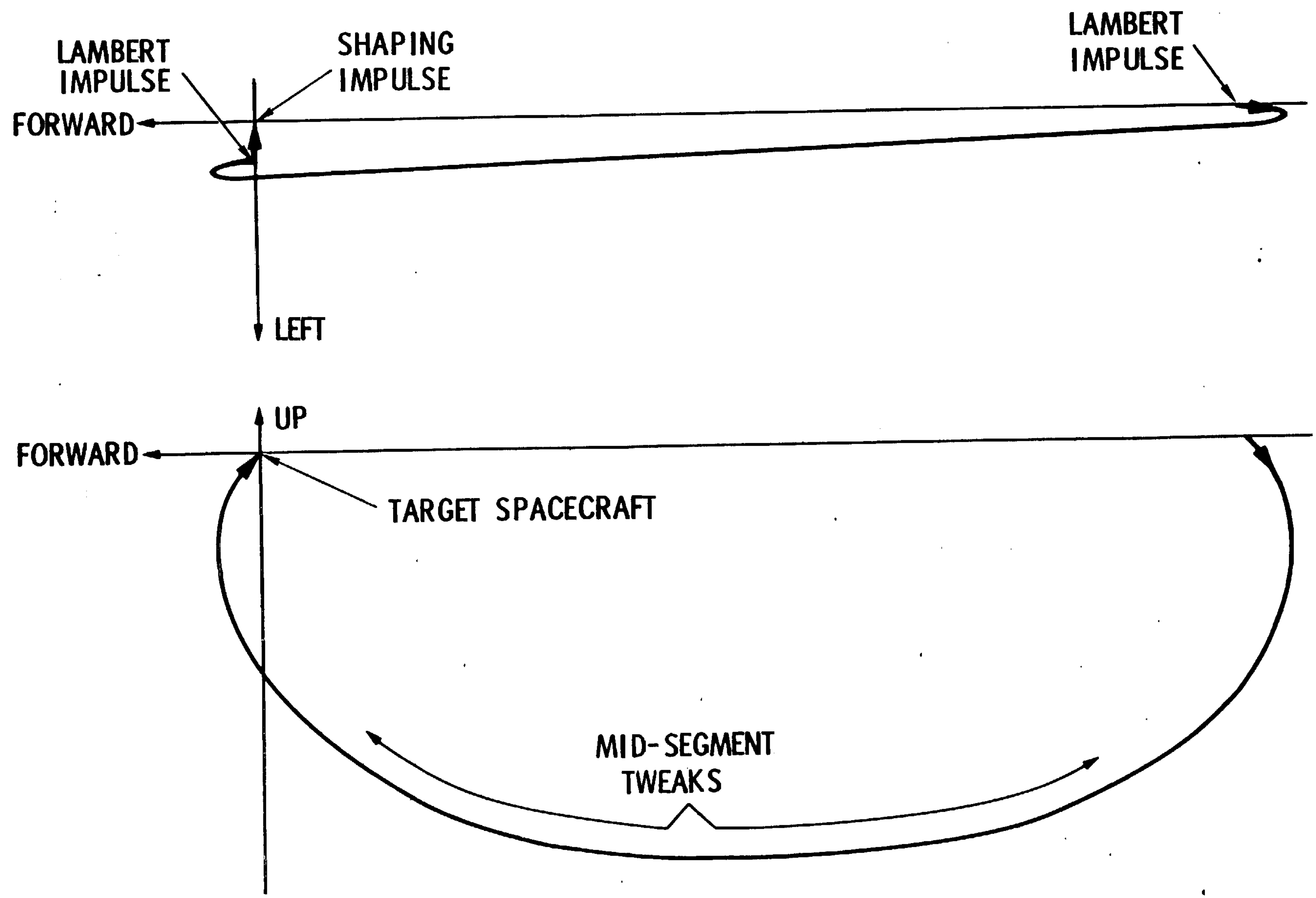
- TRAJECTORY SHAPING GUIDANCE TO MEET GEOMETRY CONSTRAINTS IN A SINGLE ORBIT
- ENROUTE CORRECTION CAPABILITY TO ADHERE TO PLANNED TRAJECTORY IN THE PRESENCE OF ATMOSPHERIC DRAG, DESPITE GUIDANCE APPROXIMATIONS
- RENDEZVOUS AND DOCKING SENSOR TO MEASURE RELATIVE POSITION AND ATTITUDE OF OTHER SPACECRAFT

CURRENT TECHNOLOGY GUIDANCE APPROACH ALONG ORBIT NORMAL

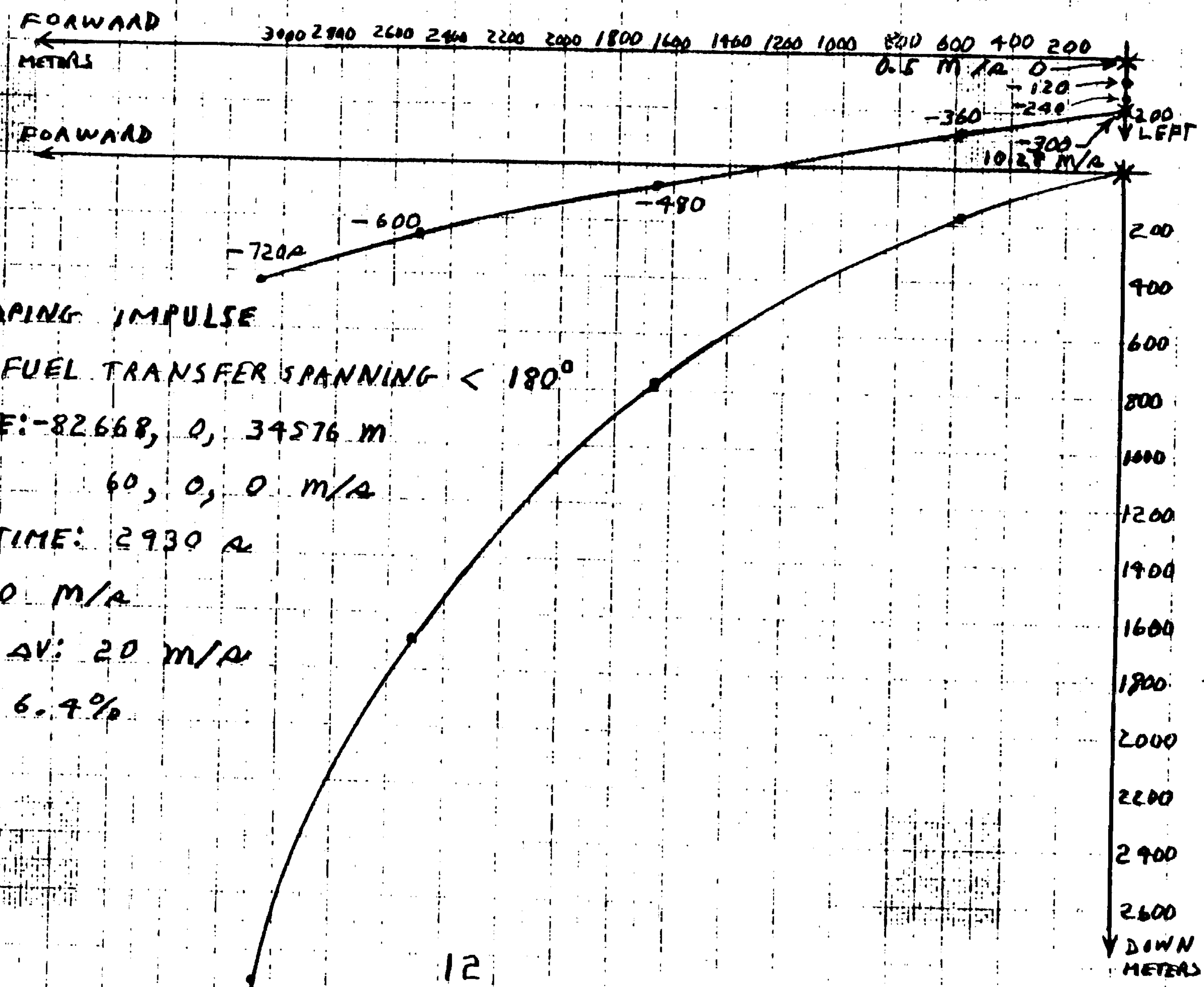
JPL



TRAJECTORY SHAPING RENDEZVOUS GUIDANCE APPROACH ALONG ORBIT NORMAL



A 3-D APPROACH



SINGLE SHAPING IMPULSE

MINIMUM FUEL TRANSFER SPANNING < 180°

INITIAL STATE: -82668, 0, 34576 m

60, 0, 0 m/s

TRANSFER TIME: 2930 s

ΔV: 21.280 m/s

HOHMANN ΔV: 20 m/s

PENALTY: 6.4%

12

A GRADUALLY BRAKED PLANAR APPROACH

THREE SHAPING IMPULSES

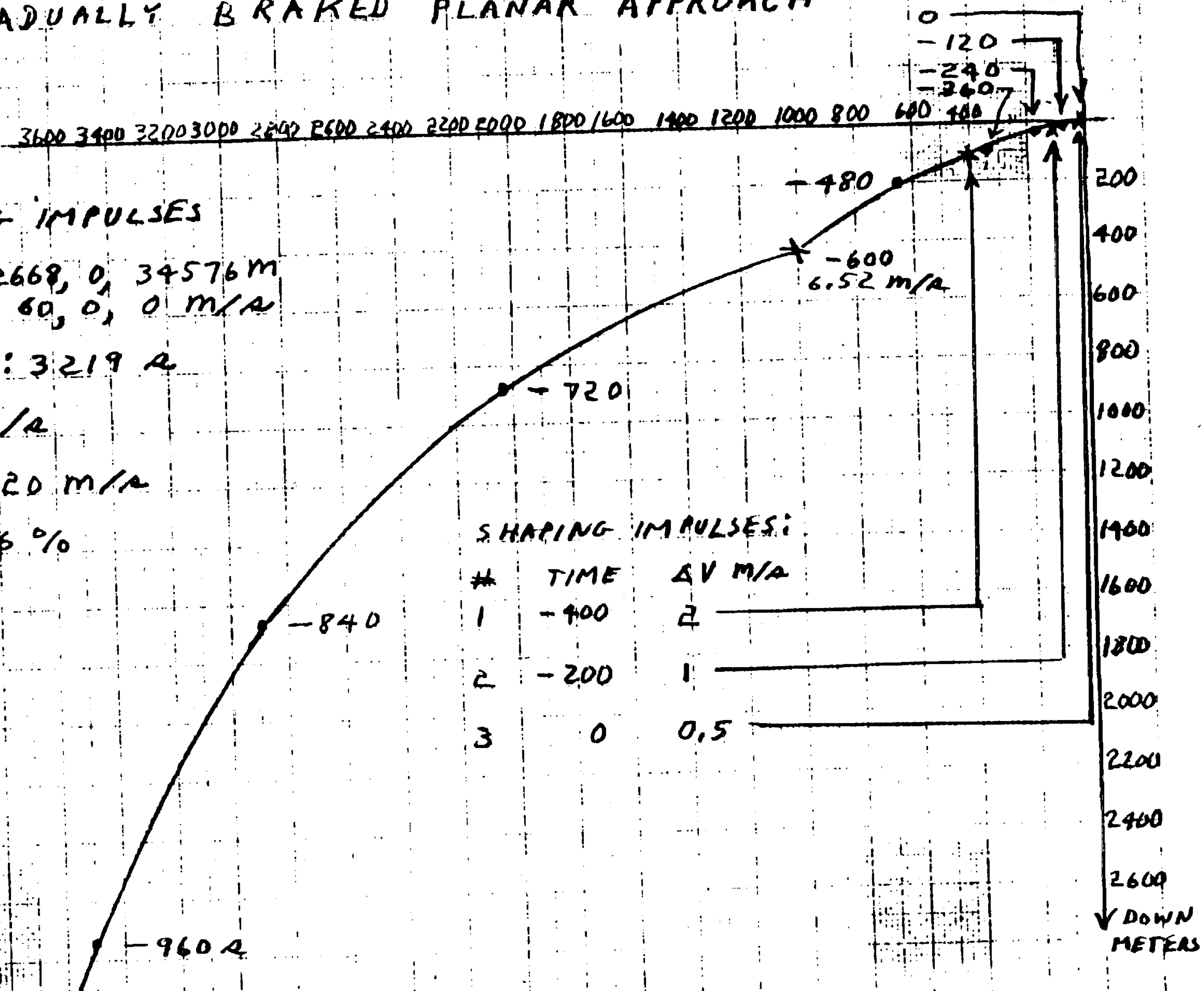
INITIAL STATE: -82668, 0, 34576 M
60, 0, 0 M/A

TRANSFER TIME: 3219 A

ΔV: 20.172 M/A

HOHMANN ΔV: 20 M/A

PENALTY: 0.86 %



JPL

A NEEDED RENDEZVOUS G&N TECHNOLOGY DEVELOPMENT PROGRAM

- PURPOSE: DEVELOP RENDEZVOUS G&N TECHNOLOGIES REQUIRED TO MAKE RENDEZVOUS A SAFE, FAST, COMMONPLACE OPERATION

- PRODUCTS: G&N SOFTWARE MODULES TO BE USED IN SIMULATIONS AND, ULTIMATELY, IN FLIGHT; RENDEZVOUS AND DOCKING SENSOR

- LANGUAGE: ADA OR HAL/S

SESSION 5A - MECHANISMS

MANIPULATORS

FOR

BERTHING/DOCKING

AGENDA

- OBJECTIVE
- BACKGROUND
- DOCKING PROBLEMS
- SATELLITE CONFIGURATIONS
- TYPICAL GUIDELINES & TRADES
- CONCEPTS
- LARGE SPACE SYSTEMS
- CONCLUSIONS

OBJECTIVE

- THE MAJOR OBJECTIVE IS TO IDENTIFY THE PARTICULAR DESIGN CONCERNS IN DEFINING MANIPULATORS THAT ADDRESS THE PROBLEMS OF DOCKING/BERTHING FOR A WIDE RANGE OF SPACE VEHICLES.

PRIOR STUDIES

STUDY TITLE/COMPANY	DATE/ CONTRACT #	APPLICABLE CONTENTS
PRELIMINARY DESIGN OF A SHUTTLE DOCKING AND CARGO HANDLING SYSTEM, MMC	1971 MSC 05218	SHUTTLE DOCKING AND CARGO HANDLING ANALYSES
CONFIGURATION AND DESIGN STUDY OF MANIPULATOR SYSTEMS APPLICABLE TO THE FF TELEOPERATOR	1974 NAS8-30266	DOCKING REQUIREMENTS AND CONCEPTS
SPACE TUG AUTOMATIC DOCKING CONTROL STUDY, LOCKHEED MISSILES AND SPACE COMPANY	1974	DOCKING CONCEPTS DOCKING REQUIREMENTS
IUS/TUG PAYLOAD REQUIREMENTS COMPATIBILITY, McDONNELL DOUGLAS ASTRONAUTICS	1975 NAS8-31013	DOCKING CONCEPTS DOCKING REQUIREMENTS
SPACE TUG AVIONICS DEFINITION STUDY, GENERAL DYNAMICS/ CONVAIR DIVISION	1975 NAS8-31010	DOCKING REQUIREMENTS DOCKING CONCEPTS FOR DEPLOY/ RETRIEVE TUG/PAYLOADS
INTEGRATED ORBITAL SERVICING STUDY, MARTIN MARIETTA CORP.	1975 NAS8-30820	DOCKING CONCEPT ASSOCIATED WITH SERVICING
EARTH ORBITAL TELEOPERATOR SYSTEMS CONCEPTS AND ANLYSIS,	1976 NAS8-31290	DOCKING CONCEPTS, DOCKING RETRIEVAL MECHANISM, LAB MODEL
SPACE TUG DOCKING STUDY, MARTIN MARIETTA CORPORATION	1976 NAS8-31542	RENDEZVOUS, CAPTURE AND DOCKING TECHNIQUES AND REQUIREMENTS DOCKING CONCEPTS
ORBITAL CONSTRUCTION SUPPORT EQUIPMENT (OCSE), MARTIN MARIETTA CORPORATION	1977 NAS9-15120	ORBITAL CONSTRUCTION SCENARIOS LARGE SPACE SYSTEMS JOINING CONCEPTS
DOD/STS ON-ORBIT ASSEMBLY CONCEPT DESIGN	1978 F04701-77-C-1080	ORBITAL ASSEMBLY SCENARIOS FOR LSS CONCEPT

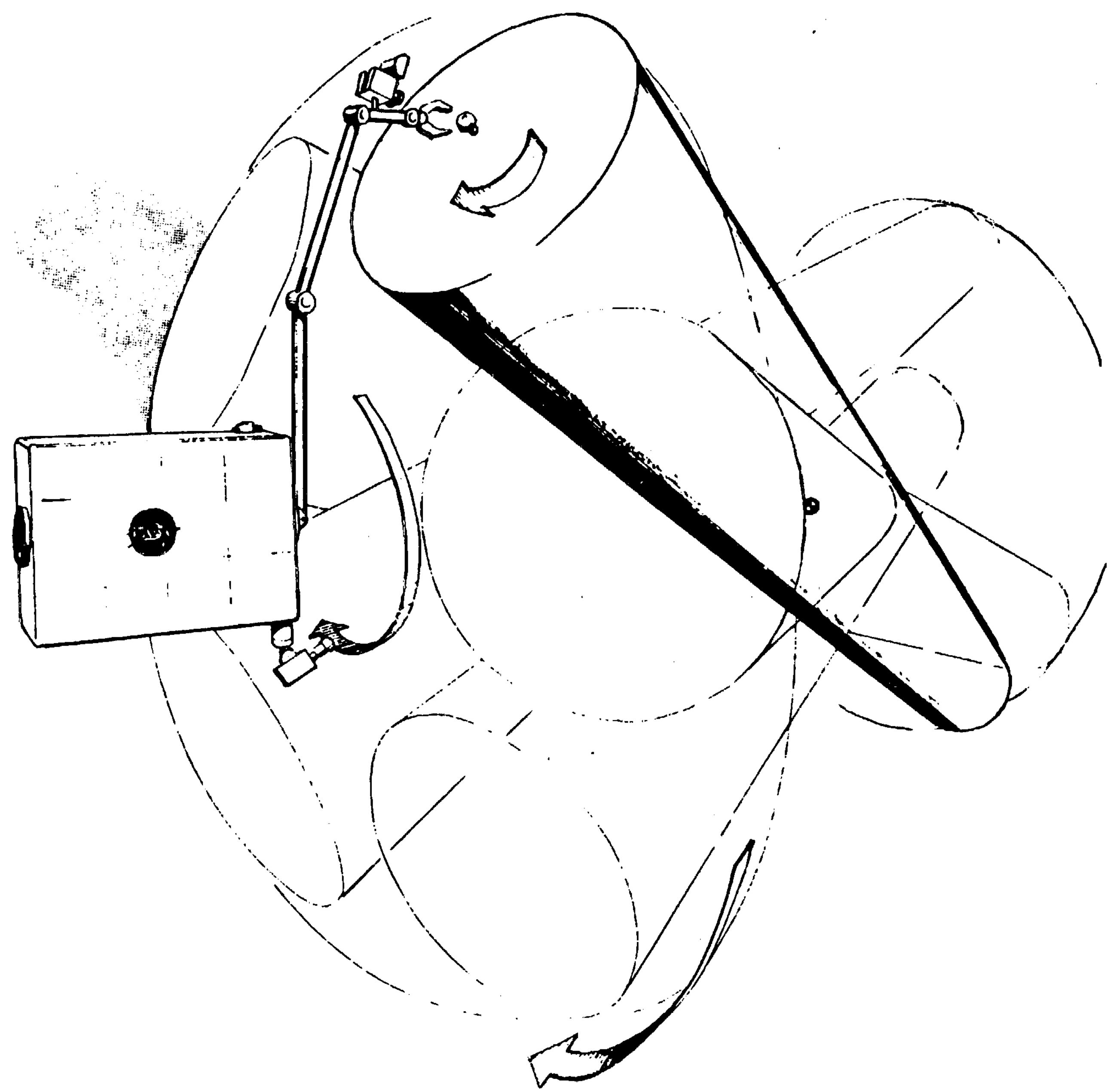
DOCKING PROBLEMS

- SYSTEM LEVEL CHARACTERISTICS
  - APPROACH TECHNIQUE
  - CONTROL METHODS
  - DYNAMIC STATE
  - TIME CONSTRAINTS

- PHYSICAL CONSIDERATIONS
  - GENERIC CLASSIFICATIONS
    - CENTROIDAL
    - PERIPHERAL
    - EXTERNAL GRASPING
    - EXTERNAL ENVELOPING
    - INTERNAL EXPANSION
    - COMBINATION

  - TARGET AND CHASE VEHICLE RELATIVE SIZES
    - TARGET LARGE, CHASE SMALL
    - TARGET SMALL, CHASE SMALL
    - TARGER SMALL, CHASE LARGE
    - TARGET LARGE, CHASE LARGE

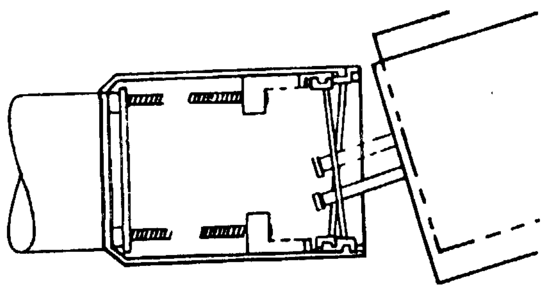
NUTATING SPINNING SATELLITE CAPTURE



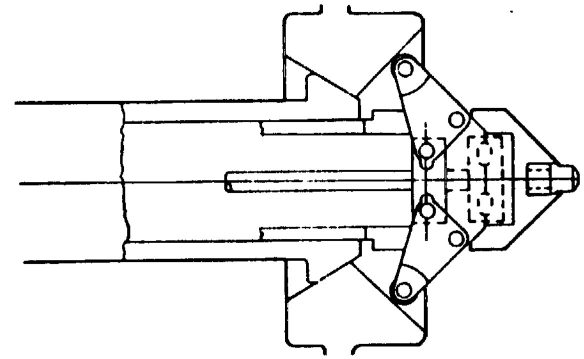
SATELLITE CONFIGURATIONS

- STABILIZATION MODE
- DOCKING OR GRASPING PROVISIONS
- SHAPE AND SIZE
- SEARCH AIDS
- REMOTE CONTROL CAPABILITY
- SHOCK SENSITIVITY

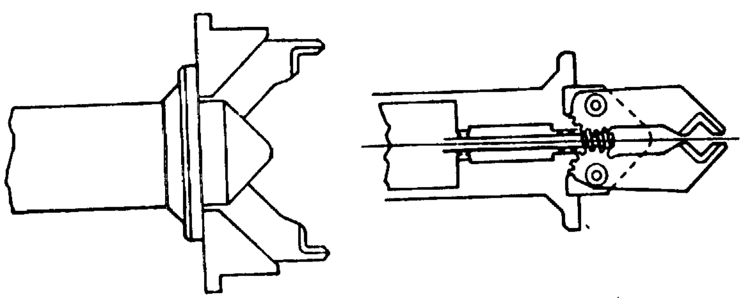
CENTROIDAL



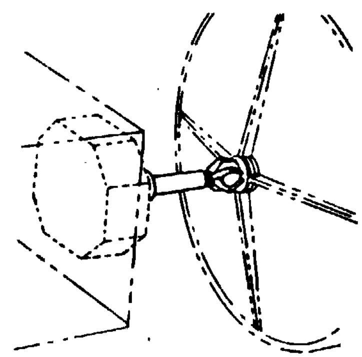
CABLE SNARE



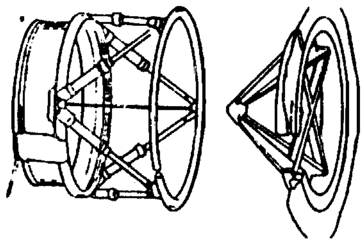
FORWARD PIVOT FINGERS



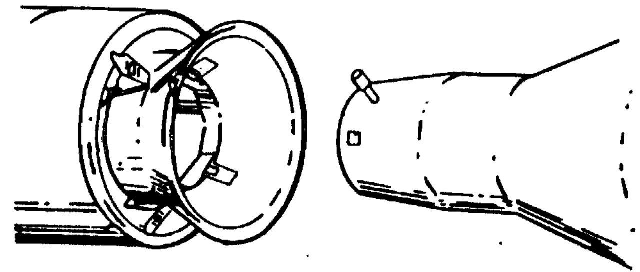
DUAL FUNCTION



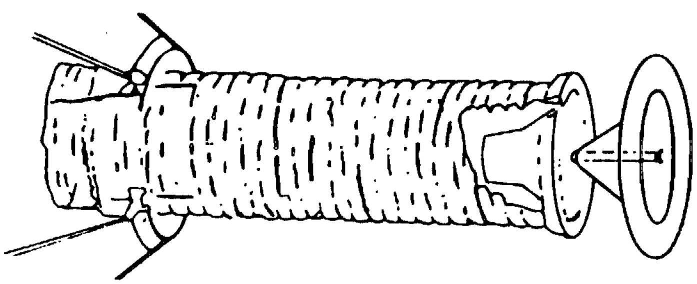
MULTIFINGER CLAW



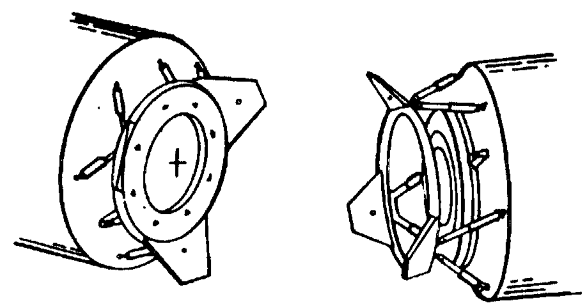
RING AND CONE



GEMINI

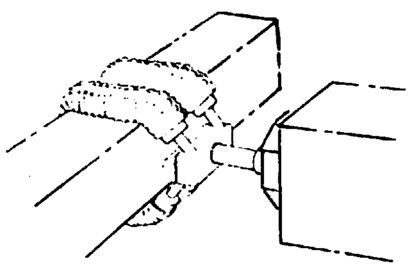


INFLATABLE TUNNEL

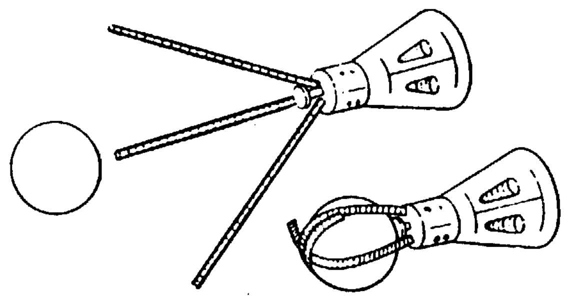


ASTP

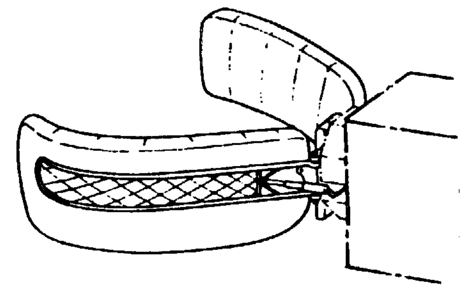
EXTERNAL ENVELOPING



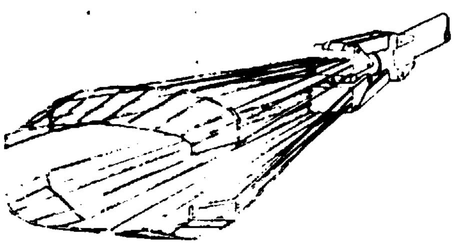
INFLATABLE ARMS



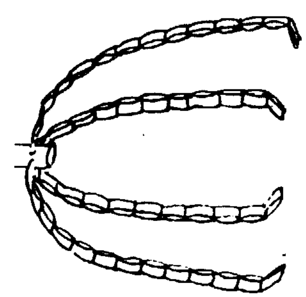
SPACE BOLA



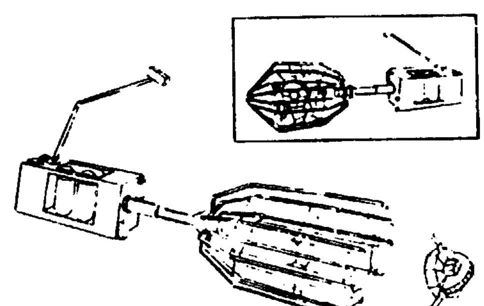
COMPLIANT ARMS



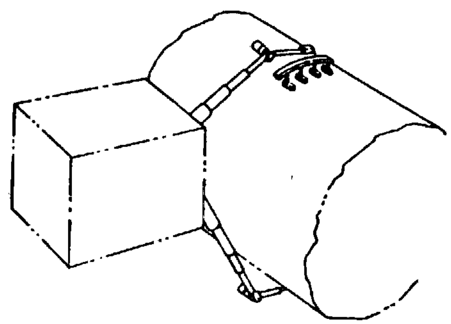
SPLIT BASKET



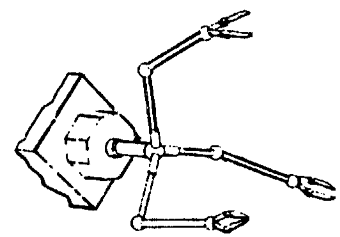
MULTISEGMENTED ARMS



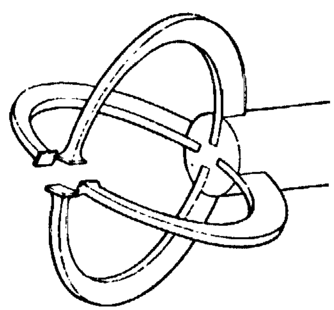
MSFC SNARE



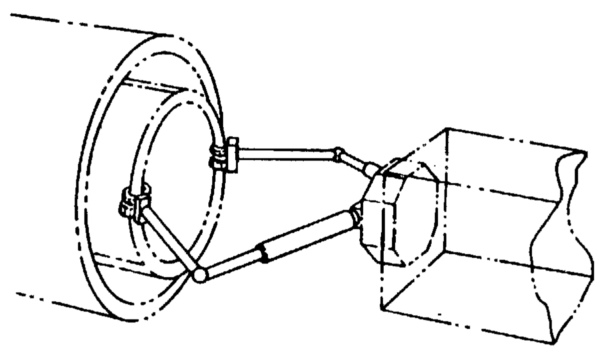
JOINTED OR TELESCOPING ARMS



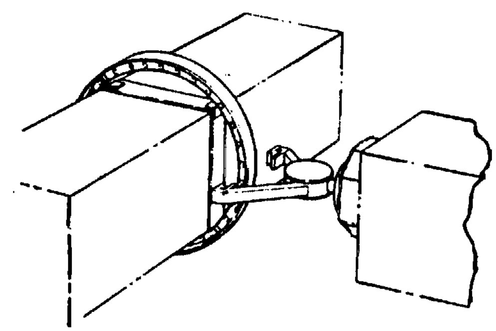
MULTI MANIPULATOR ARMS



C-CLAMP

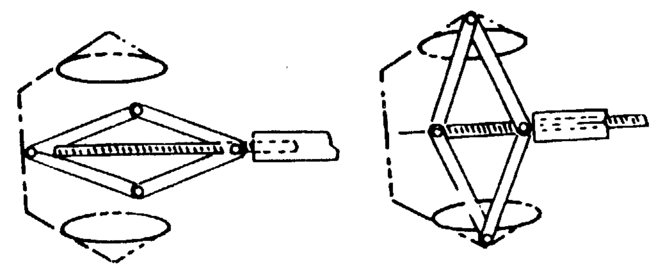


INFLATABLE FINGERS

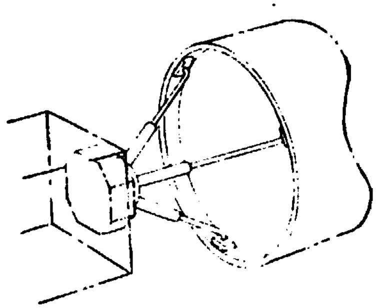


SPLIT JAW

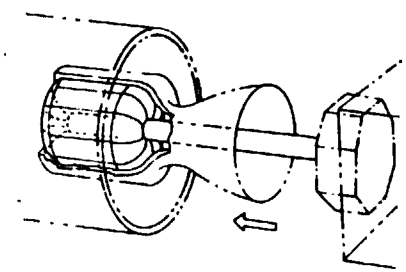
INTERNAL EXPANSION



EXPANDING LINKAGE

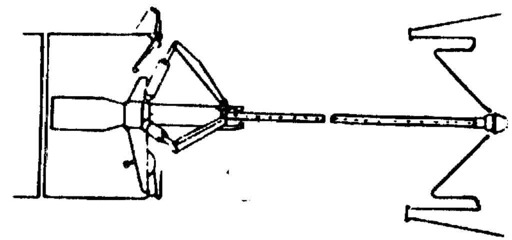


TELESCOPING ARMS

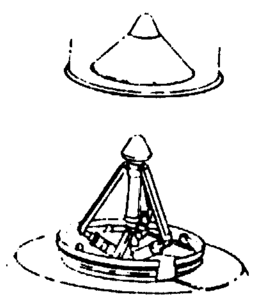


INFLATED BALLON

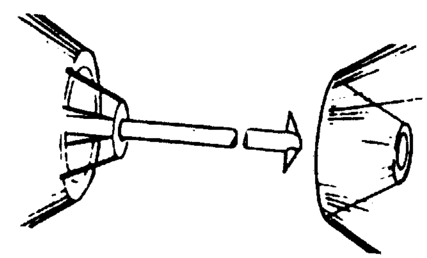
COMBINATION (HYBRID)



STEM AND CABLE

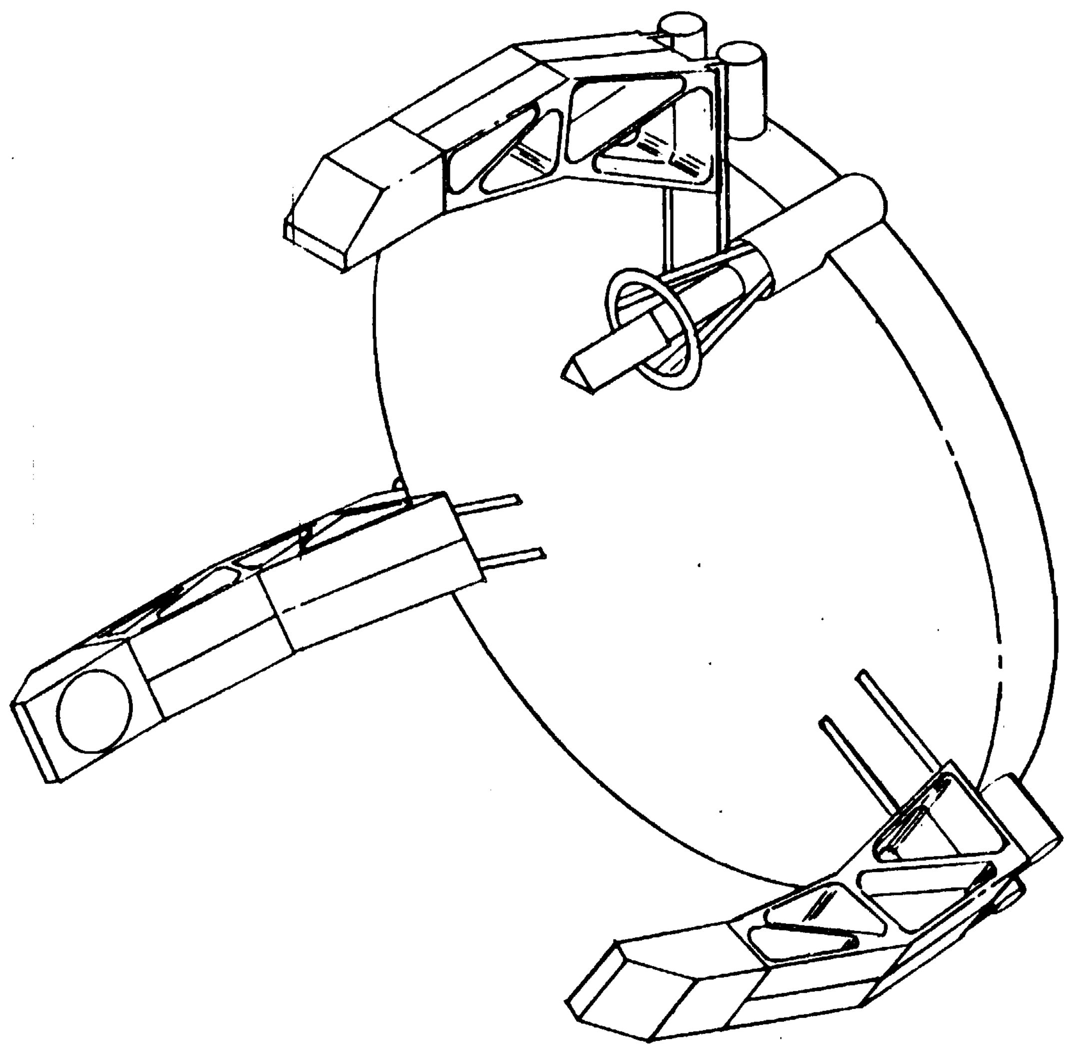


PROBE AND DROGUE



INFLATABLE PROBE

3 ARM DOCKING CLAMP AND PROBE



TYPICAL GUIDELINES/TRADE STUDIES

TYPICAL GUIDELINES

- ALLOW VISUAL MONITORING OF DOCKING OPERATIONS
- ACCOMMODATE VARIATIONS IN INITIAL CONDITIONS
- SUPPORT ALL ANTICIPATED LOADS
- ACCOMMODATE FOR MISSED DOCKING SEQUENCE
- PROVIDE FOR PROGRESSIVE AUTOMATION
- BERTHING MECHANISM HALVES TO BE IDENTICAL AND ANDROGYNOUS (SS UNIQUE)

TRADE STUDIES

- ACTIVE VS PASSIVE CONSIDERATIONS
- NUMBER OF DOF AND JOINT ORDER
- IMPACT VS NONIMPACT
- ENVELOPING VS INTERNAL CAPTURE/LATCH
- SIMULTANEOUS VS SEQUENTIAL CAPTURE/LATCH
- SINGLE VS MULTIPLE ARMS
- DEGREE OF AUTOMATION
- OTHER TECHNIQUES

DOCKING MANIPULATOR DOF

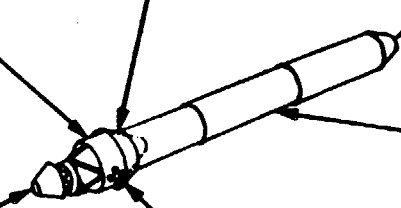
SATELLITE	DOF	FUNCTION
STABLE	1	PROVIDE STRUCTURAL ATTACHMENT
SPINNING	1	DESPIN TORQUE
	2	GRIP AND STRUCTURAL ATTACHMENT
TUMBLING	2	BASE - CIRCULAR MOTION
	1	ELBOW - REACH CONTROL
	1	WRIST - INTERFACE ALIGNMENT
	2	WRIST - GRIP AND STRUCTURAL ATTACHMENT
SPINNING & TUMBLING	2	BASE - CIRCULAR MOTION
	1	ELBOW - REACH CONTROL
	1	WRIST - INTERFACE ALIGNMENT
	1	WRIST - DESPIN TORQUE
	2	WRIST - GRIP AND STRUCTURAL ATTACHMENT

DOCKING LARGE SYSTEMS

- Provide Techniques/Systems To Join Large ($>10^5$ KG Mass, Dimensions >500 Meters) Structures
- Provide At Least Three Points Of Contact
- Utilize Existing Docking Technology To Develop Universal System
- Utilize Existing And State-Of-The-Art Sensor Technology To Optimize Technique

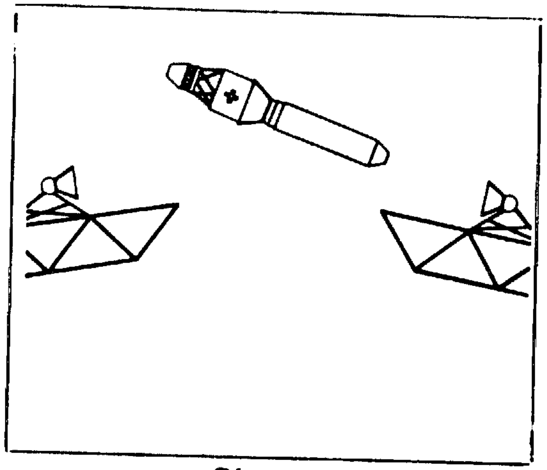
MARTIN MARIETTA

BOEING DOCKING MODULE

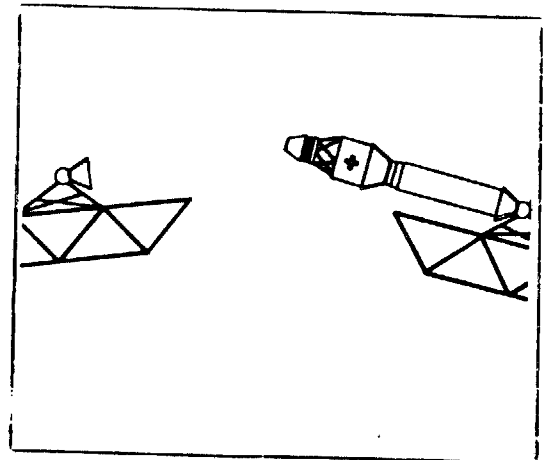


MARTIN MARIETTA

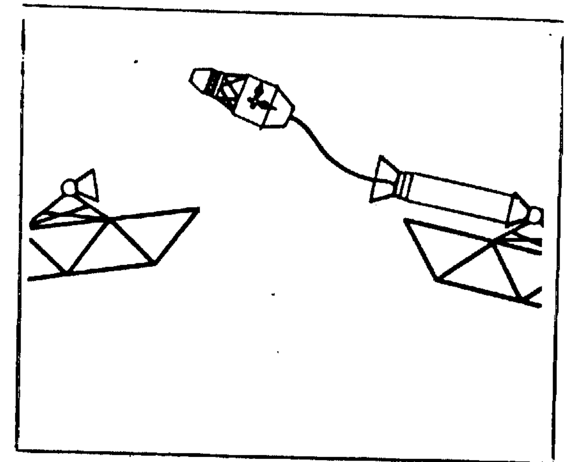
DOCKING SEQUENCE - BOEING CONCEPT



Step 1



Step 2



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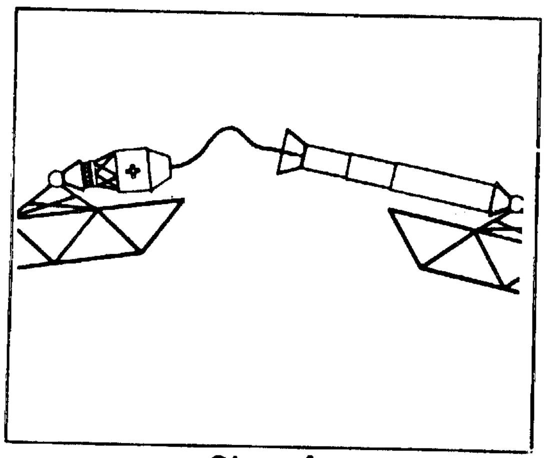

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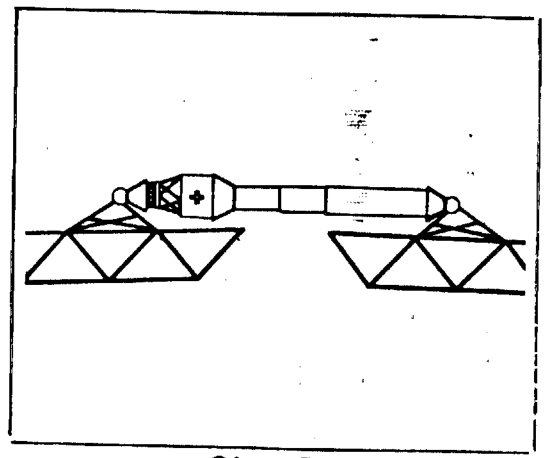

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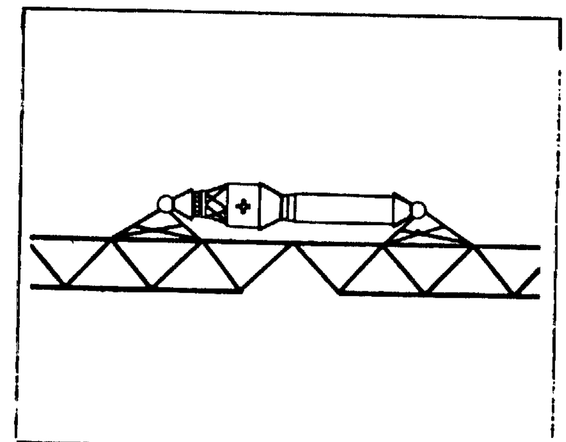
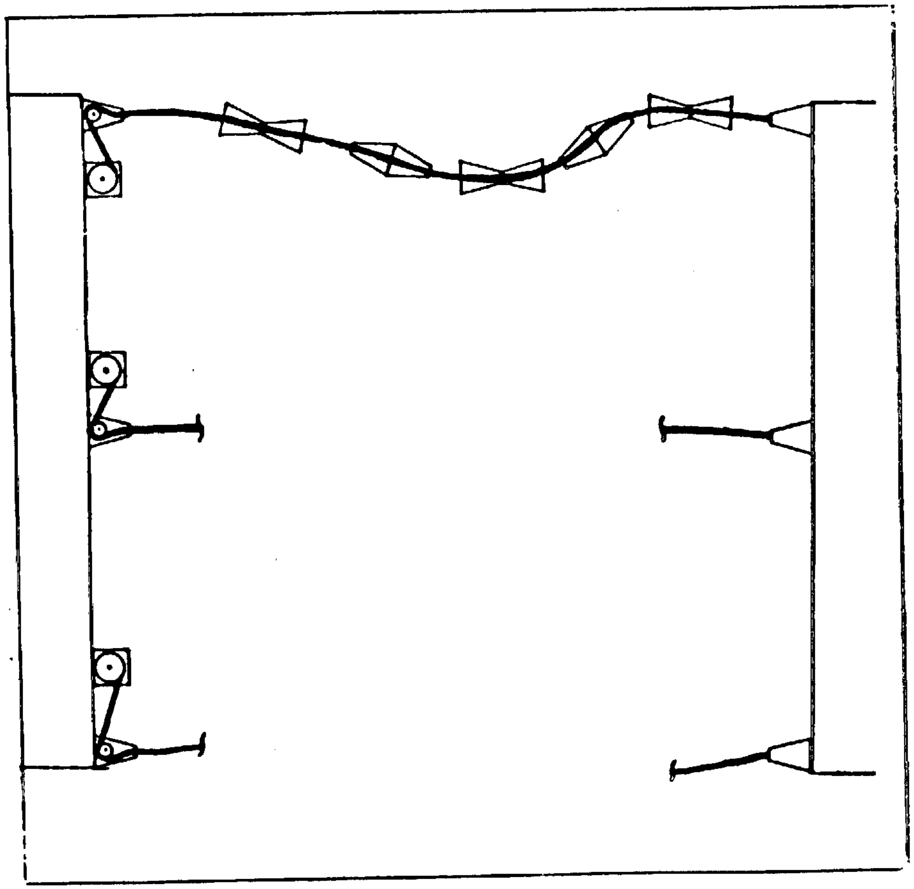


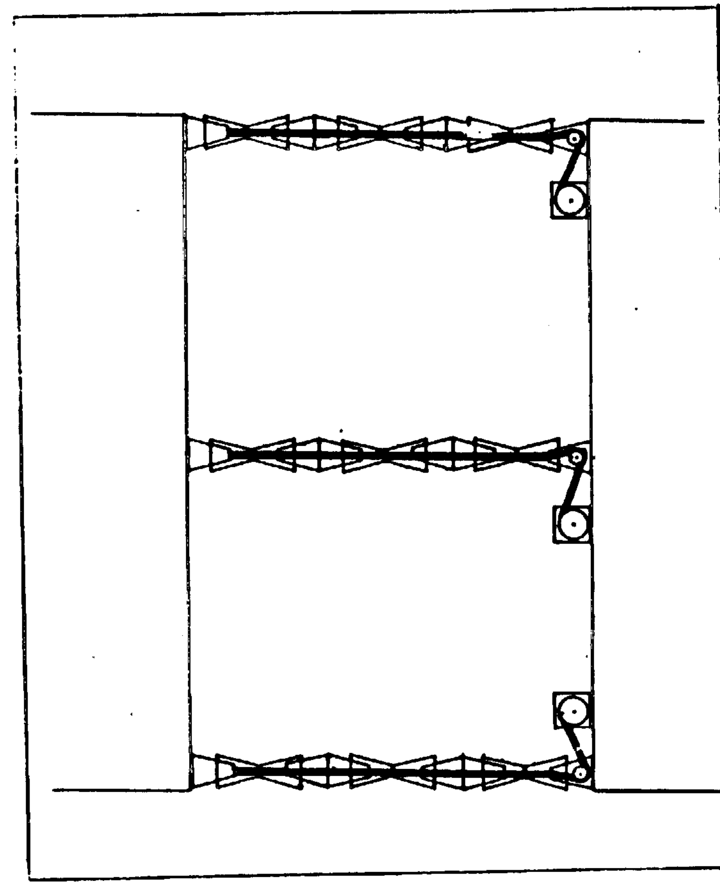
Step 6

MARTIN MARIETTA

CABLE DOCKING



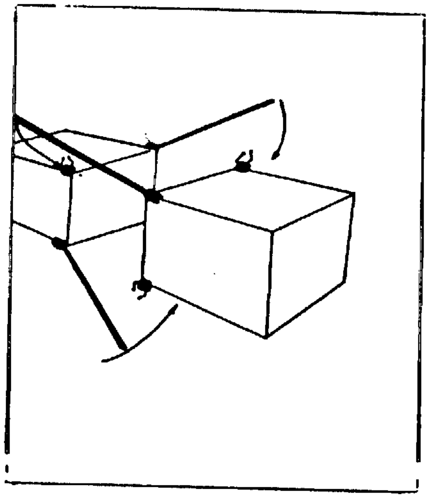
Self-Aligning Guides On Cables-
Strung Between Structures



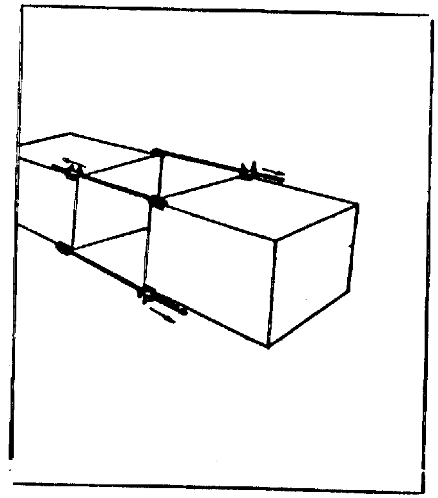
Guides Form Spacing Beams
Until Structures Are Attached

MARTIN MARIETTA

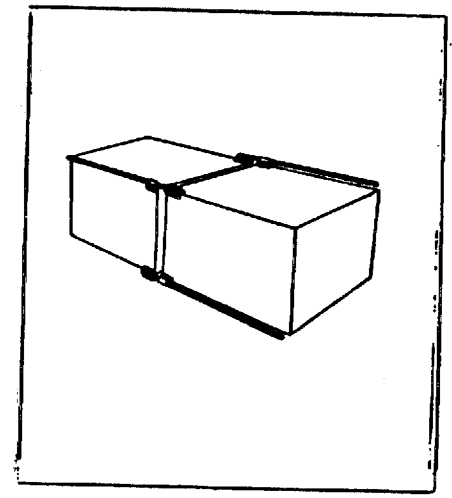
LONG BOOM DOCKING



Booms Manipulated To Span Structures



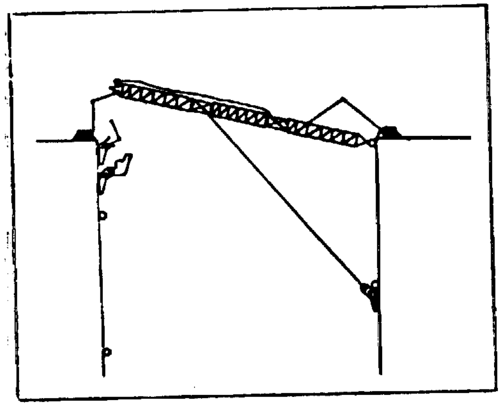
Boom-Mover Machines Pull Structures Together



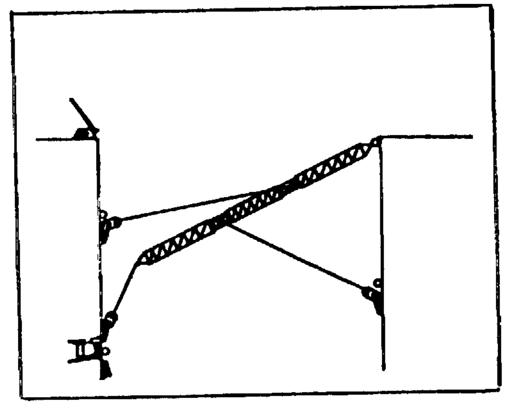
Permanent Joint Established

MARTIN MARIETTA

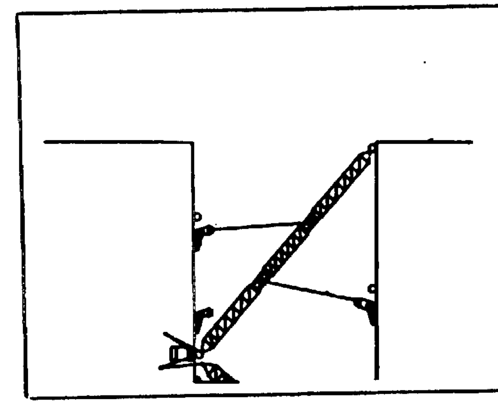
LONG BOOM/STRUCTURE DOCKING



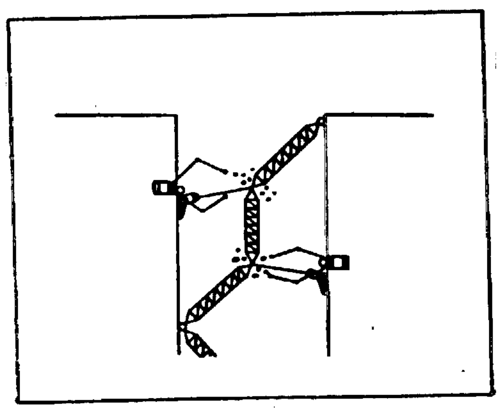
Step 1: Booms Spans Structure



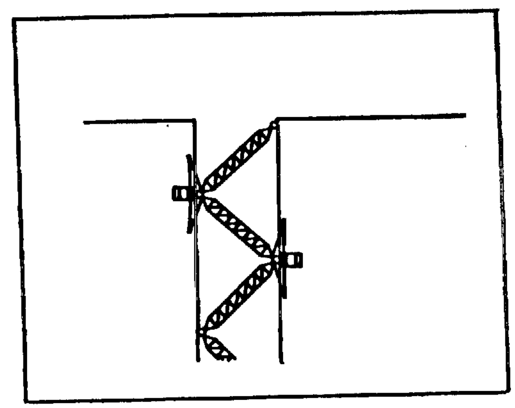
Step 2: Cables Pull Structure Together



Step 3: Boom Attached



Step 4: Joint Restrainers Broken



Step 5: Cables Pull Other Joints Into Position

MARTIN MARIETTA

CONCLUSIONS

- MANIPULATORS/MECHANISMS MUST PLAY A MAJOR ROLE IN DOCKING ACTIVITIES
- MANIPULATORS USED IN DIFFICULT DOCKING ACTIVITIES SHOULD INCLUDE SUCH SAFETY FEATURES AS BACKDRIVEABILITY, ATTENUATION, SHOCK ABSORBERS, SAFETY RELEASE DEVICES, ETC.
- MANIPULATORS USED FOR DOCKING FALL INTO THREE BASIC LEVELS OF COMPLEXITY
- AUTOMATIC CONTROL SYSTEMS MUST BE INCORPORATED INTO THE PROCESS WHENEVER PRACTICAL

The Payload Deployment/Retrieval Performance of The Space Shuttle Remote Manipulator System

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Rendezvous and Proximity Operations Workshop

NASA Johnson Space Center

February 20, 1985

5A-25

THE PAYLOAD DEPLOYMENT/RETRIEVAL PERFORMANCE OF THE SPACE SHUTTLE REMOTE MANIPULATOR SYSTEM

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Abstract

The payload deployment and retrieval performance of the Space Shuttle Remote Manipulator System is addressed in terms of system requirements and on-orbit performance based on downlisted flight data. Typical flight data is presented. Issues of concern in payload deployment and retrieval are discussed. A technique for estimating the payload tip-off rate and a payload release procedure are recommended.

Two possible future augmentations to the Shuttle Remote Manipulator System to improve its payload deployment and retrieval capability are described: Force Sensor-Accommodation System and Space Vision System.

INTRODUCTION

The Shuttle Remote Manipulator System (SRMS) is designed primarily for the deployment and retrieval of payloads from and to the Orbiter cargo bay. To date, a number of payloads have been successfully deployed or retrieved by the SRMS as shown in Table 1. In terms of historical events, LDEF is the heaviest payload that has been deployed by the SRMS, whereas the troubled Palapa was retrieved in a rescue mission.

At first glance, a payload deployment is simply a retrieval manoeuvre in reverse, except that they both involve a payload capture at the beginning of the manoeuvre and a payload release at the end of the manoeuvre, as depicted by Figure 1. However, from an operational viewpoint, tracking and capturing a payload outside the cargo bay requires a suitable and favourable position/attitude, as well as velocities, of the payload relative to the Orbiter; thus it is a more difficult task than to (track and) capture a payload inside the cargo bay. On the other hand, the payload tip-off rate resulting from a payload release outside the cargo bay has always been of concern since it would affect the payload motion after release, and indirectly the mission success. It is therefore logical to treat the payload deployment and retrieval separately.

As part of the SRMS on-orbit verification, downlisted SRMS data has been analysed to determine the SRMS performance during the deployment and retrieval of various payloads. Attention is focused on the following issues:

- Contact between the SRMS end effector and the payload grapple fixture during release;

- Payload tip-off rate;

- End effector and payload motion prior to, during and after capture or release; loads induced in the SRMS arm during the arm rigidization, subsequent to the payload capture;

- Loads induced in the SRMS arm during payload berthing and unberthing due to contact between the payload and its trunions.

Typical results from the above analysis are presented in this paper. In order to provide a proper perspective of the payload deployment and retrieval operations, the operational procedures and constraints will be discussed briefly. Two possible future augmentations to the SRMS to improve its payload deployment and retrieval capability will also be discussed.

End Effector and Payload Grapple Fixture

Two key elements in a payload deployment or retrieval are the SRMS end effector and the payload grapple fixture although the SRMS and Orbiter Closed-Circuit Television camera systems also play no less an important role. Figure 2 depicts a grapple fixture with the grapple target, both of which must be mounted on the payload by the payload user in such a location that the SRMS end effector can grapple the fixture shaft with sufficient clearance to avoid collision with the payload. Figure 3 shows a cut-away view of the SRMS end effector.

The payload capture consists of a **capture** phase in which the end effector snare wires are commanded to close in to capture the grapple shaft, followed by a **rigidization** phase in which the carriage draws the snare assembly to the end of its travel and upon the completion of the rigidization phase, a constant force is applied by the end effector motor onto the grapple fixture to keep it "rigidly" attached to the end effector. It is in this rigidization phase that the pitch/yaw/roll misalignment error between the end effector and the payload grapple fixture is corrected automatically; the roll misalignment can be nulled by the SRMS operator if desired.

The payload release consists of a **derigidization** phase in which the carriage is commanded towards the opening of the end effector until it reaches its zero-tension point, followed by a **release** phase in which the snare wires are

commanded to open. The release phase is terminated when the snare wires are fully open and the end effector is withdrawn from the grapple fixture.

The payload capture/rigidization and derigidization/release can be commanded either in automatic mode or in manual mode. In the automatic mode, the above operations are done sequentially and automatically upon the selection of the AUTO, RIGID/DERIGID switches on the SRMS Display and Control Panel. In the manual mode, the capture or release command is given by triggering the CAPTURE/RELEASE switch on the SRMS Rotational Hand Controller and the rigidization or derigidization is commanded by selecting the RIGID/DERIGID switch on the SRMS Display and Control Panel. In the manual mode, the commands are effective only when the switches are operated. Micro-switches in the end effector provide necessary data to the Orbiter General Purpose Computer so that the status of payload capture/release can be fully monitored.

Payload Capture/Release Constraints

In order to avoid collisions between the end effector and the payload during tracking of a payload, to maintain the structural integrity of the SRMS arm, and to ensure the mission success, there are a number of operational constraints placed on the SRMS, the payload and the Orbiter for payload capture and release:

1. SRMS

   - The relative velocity between the end effector and the payload grapple fixture at capture must not exceed 0.4 ft/sec.

   - During tracking, the end effector must be within the payload clearance envelope shown in Figure 4.

   - Payload capture is permitted only when the misalignment errors between the end effector and the grapple shaft are less than their limits:

     Roll (about the end effector axis) $\pm$ 10°
     Pitch/Yaw (normal to the end effector axis) $\pm$ 15°
     and the grapple fixture tip must be within a circular cylinder 8 inches in diameter, 4 inches in height and 1.8 inches inside the end effector.

   - No payload capture shall be attempted if the SRMS arm is in Control Singularity, or if any of the SRMS joints is at its reach limit.

2. PAYLOAD

- Payload dimension should be within the envelope 12' 8" in diameter and 59' in length.

- Payload mass should be less than 32000 lbs for retrieval and 65000 lbs. for deployment.

- Prior to grappling, the payload must be stabilized with respect to its own inertial or local vertical reference frame, exclusive of Orbiter RCS impingement effects, as follows:

  (a) Actively Stabilized:

  - Attitude deadband $\pm 1°$
  - Angular rate error $\pm$ 0.1°/sec
  - Allowable grapple fixture motion $\pm$ 3 inches

  (b) Passively Stabilized

  - Maximum grapple fixture motion $\pm$ 15 inches
  - Maximum grapple fixture velocity $\pm$ .05 in/sec

- At release, a 65000 lb. payload should have attitude within 5° of a specified orientation relative to the Orbiter and an angular rate relative to the Orbiter $\leq$ 0.015°/sec.

- The payload velocity with respect to the Orbiter must be within 0.1 ft/sec and 0.1°/sec for tracking and capture.

3. ORBITER

- The Orbiter RCS must be deactivated at least 10 minutes before the 65000 lb. payload is released by the SRMS.

- Prior to switching from Orbiter Primary RCS to Orbiter Vernier RCS for grappling a payload, the Orbiter shall be stabilized with respect to its own inertial or local vertical reference as follows:

- Attitude deadband $\pm$ .1°/sec
- Angular rate error (maximum limit cycle rate) $\pm$ 0.1°/sec/axis

Prior to each mission with payload capture/release, extensive computer simulations have been carried out to determine the favourable arm configurations for capture/release, the associated time line and the loads induced in the SRMS. The simulation results were analysed to verify that the above requirements were satisfied and a procedure was developed which finally was incorporated in the PDRS (Payload Development and Retrieval System) Operations checklist.

Flight Data Analysis

A partial list of SRMS downlisted data is presented in Table 2 where only those variables relevant to the payload capture/release are shown. In this paper, the flight data for the SPAS-01 capture/release outside the cargo bay and the PFTA capture inside the cargo bay are presented for illustrative purposes.

Capture of Rotating SPAS-01

As part of a series of on-orbit tests, the SPAS-01 was spun up to 0.1 deg/sec over the cargo bay in STS-7 Day 5 and then captured by the SRMS at 173: 12: 33: 18 GMT. Figure 6 shows the variation of the SPAS-01 body rates throughout the capture/rigidization as recorded by its gyros. The capture and rigidization took place in approximately 13 seconds which is normal. The end effector snare wires came in contact with the SPAS-01 grapple fixture at approximately 2 seconds after the CAPTURE command was issued. Note the variation of the SPAS-01 spin vector as the end effector carriage pulled the grapple fixture into the end effector. After the end effector RIGIDIZATION flag came on, the SRMS arm was rigidized by raising its joint current limits to normal operation levels. This arm rigidization caused oscillations in the SPAS-01 body rates momentarily. SPAS-01 came to rest 10 seconds later.

The arm motion during the capture/rigidization can be reconstructed using the time histories of the six SRMS motor rates shown in Figure 7. The spikes in the motor rates occured when the SPAS-01 grapple fixture was centred inside the end effector by the end effector snare wires in the capture phase, and when the SPAS-01 was aligned to the end effector at the end of the end effector rigidization. Due to the fairly high gear ratios (1842:1 at the shoulder and 737:1 at the wrist) the joint angular rates were actually low during the capture and rigidization. The above joint motions are a result of the motors being backdriven by the end effector as the arm remained limp, as it should, during the capture and rigidization. Note that the end effector angular velocity with respect to the Orbiter, based on the motor rates and computed for the segment

after the completion of end effector rigidization, agrees very well with the SPAS-01 gyro data when the orbital component in the latter was removed. As a matter of fact, excellent correlation between the SPAS-01 gyro data and the end effector angular velocity was found in all the segments of the flight in which SPAS-01 was attached to the SRMS arm. Consequently, the end effector angular rates can be used to estimate the payload angular rates fairly accurately prior to a payload release. This technique was actually used to estimate the LDEF tip-off rate based on the downlisted SRMS data.

SPAS-01 Release

SPAS-01 was released five times during the STS-7 mission. The data for release No. 1 is selected in this paper for illustrative purposes. In this release, SPAS-01 was released over the cargo bay in Automatic mode at 173:8:3:58 GMT. The SPAS-01 angular rate before and after release is shown in Figure 8 in which the SPAS-01 angular rate based on the SRMS motor rates is superimposed with the SPAS-01 gyro data (marked with triangles Δ) for comparison. The DERIGIDIZATION flag comes on at 60 seconds, prior to which the gyro data and the SRMS - estimated payload angular rates agree fairly well. The z component of the SPAS-01 angular velocity contains the orbital rate of approximately 0.066°/sec. since the Orbiter was stabilized in LVLH (Local Vertical Local Horizontal) mode prior to SPAS-01 release.

In terms of disturbances to the payload prior to release, the SRMS brakes were disengaged at 42 seconds in this release. The discharge of the integral trim in the SRMS servo produced small torques which were large enough to overcome the motor friction and caused momentary joint motions as seen in Figure 8. In other releases, the Orbiter VRCS jet firings after tightening the deadbands caused disturbances to the payload; and small uncommanded motions of the end effector, as it was withdrawn during payload release, might have caused slight contact between the grapple fixture cam and the end effector opening ring. Based on the above observations, it has been recommended that payload release be delayed when performed after BRAKE OFF or Orbiter RCS attitude and rate deadband tightening, and the end effector back-off be done gently.

Insofar as the verification of the payload tip-off rate is concerned, the requirement mentioned previously can be phrased in a slightly different but equivalent manner as follows. The payload angular momentum relative to the Orbiter must not exceed 15 ft-lbs-sec at release. In this connection, the payload angular momentum relative to the Orbiter, and with respect to the payload centre of mass, has been computed for different releases. Figure 9 shows the SPAS-01 relative angular momentum magnitude during release number 1, based on SPAS-01 gyro data. The peak value of the angular momentum is less than 3.25 ft-lb-sec; thus, the tip-off rate requirement is satisfied in this release. Figure 10 shows the same angular momentum magnitude computed from the

SRMS-estimated end effector rate. The agreement between Figures 9 and 10 provides justification for using SRMS data to estimate the tip-off rates for other payloads which do not have instrumentations for measuring their angular rates.

PFTA Capture In Cargo Bay

In the absence of strain gauges in STS-7, the loads induced in the SRMS arm due to the capture and rigidization of SPAS-01 could not be studied. In order to show typical arm loading due to payload capture, the capture of the PFTA with grapple fixture number 2 in STS-8 Flight Day 3 at 244:06:44: 15 GMT is selected. Figure 11 shows the PFTA being handled by the SRMS outside the cargo bay. The downlisted SRMS motor rates indicate that the capture/rigidization took place nominally.

The loads at the SRMS shoulder and wrist as measured by the strain gauges are shown in Figure 12. The strain gauges are installed in the electronics housing compartments near the SRMS shoulder and wrist pitch joints. In terms of the time in Figure 12, the CAPTURE flag comes on at 734.23 seconds and the RIGIDIZATION flag comes on at 747.23 seconds. The peak loads occur when the end effector attempts to centre the grapple fixture shaft by closing its snare wires and when the misalignment error of the end effector relative to the PFTA is corrected at the end of the end effector rigidization phase. The peak loads are actually one order of magnitude smaller than the allowable joint load limits used in mission planning. Note that after the arm rigidization, the induced loads vanish because the arm is at rest with respect to the (berthed) payload and the orbiter.

Possible SRMS Augmentations

At present, the SRMS operator performs the payload deployment/retrieval task relying on the visual feedback by direct vision and by the Orbiter/SRMS Closed-Circuit Television Camera Systems. In tracking of a payload, the grapple target shown in Figure 2 does provide some cues to the operator as to the relative position and attitude of the payload with respect to the end effector. However, the vision information is not quantitative, and it needs to be processed by the operator's mind to close the man-machine loop. On the other hand, during berthing and unberthing of a payload, the visual feedback mentioned above is not sufficient since the operator cannot determine whether or not the payload contacts with the Orbiter, based on the visual feedback alone. In order to enhance the SRMS capabilities and to facilitate the payload deployment/retrieval task, some research has been performed at Spar Aerospace Limited on a force sensor-feedback/accommodation system and a space vision system that can augment the SRMS.

Force Sensor - Feedback/Accommodation System

The key element in the Force Sensor - Feedback/Accommodation system is a force/moment sensor capable of measuring three-component forces and moments, which can be mounted between the SRMS wrist Roll joint and the end effector. A minimum set of three strain gauges can be suitably arranged and bonded to a "feeler" on which the force/moment is to be determined. The strain gauges are first converted to forces and moments, and then fed back to the operator, either visually through a composite analogue display of the six components of the force/moment, or by tactile means. In the latter case, the measured force and moment are reflected onto the SRMS Translational and Rotational Hand Controllers via some driving mechanism to provide a feel to the SRMS operator so that he/she can respond accordingly. Among various requirements for a hand controller with force feedback are:

i) The hand controller must be able to generate torques proportional to the input signals;

ii) The hand controller must be able to return to the null position automatically as soon as it is released;

iii) The force/torque generated on the hand controller by its servo system must be within the range that a human hand can sense (usually 0.015 lbs to 4.5 lbs.[1]) and can respond to (oscillations of 5 Hz or less, although a human hand is capable of feeling oscillations above 100 Hz [2]).

A block diagram for a Manipulator Control System using Force Feedback Hand Controllers and Resolved Rate Algorithm is shown in Figure 13. In this scheme, the SRMS operator would need to compensate for any undesired force/moment or to apply a desired one manually.

An alternative to the above scheme is the force sensor-accommodation control system whereby the measured force/moment is accommodated via an accommodation matrix specified for the task being performed. Figure 14 shows a block diagram for the Force/Moment Accommodation Control System. Force accommodation would be useful in the automatic mode of operation. In the manual mode, it could be used as an alternative to tactile force feedback in which case a provision for selecting or deselecting the force accommodation should be available.

Space Vision System

Compliance with the SRMS payload capture constraints requires the operator to estimate a payload's linear and angular velocities if this data is not telemetered. Berthing of a very large payload requires precise knowledge of the

relative position and attitude with respect to the orbiter structure. The Space Vision System (SVS), derived from a Real-time Photogrammetry System developed by the National Research Council of Canada, is designed to assist the SRMS operator in tracking and berthing payloads by providing real-time information on the payload position/attitude, linear/angular velocities relative to a selected reference frame, as well as graphically-displayed visual cues. A block diagram for the SVS is shown in figure 15. Basically, the SVS consists of a sensor unit such as the SRMS Wrist Camera, Target Arrays mounted on the payload, a Real Time Photogrammetry Unit, a dedicated Display and Control Panel and a CCTV monitor.

The SVS is capable of acquiring, locking, tracking and auto ranging a target as long as the target remains within the selected camera field of view and its details can be discriminated. Following the system initialization, the SVS operator points the selected camera to the payload-mounted target array to obtain its view on a dedicated monitor. Figure 16 shows the standard target array which consists of four target elements symmetrically arranged and located in a known position with respect to the payload axes. The operator then acquires the target elements by positioning a "window" over each element using either a light pen. The Real Time Photogrammetry Unit then starts processing the visual information and outputs the payload position/attitude, linear/angular velocities, range, bearing (azimuth, elevation), range rate, bearing rate as numerical data and visual cues through a synthetic graphic display to an Orbiter CCTV monitor. An example of a synthetic display is given in Figure 17 where misalignment errors between the camera and the target are shown graphically. Numerical outputs from the Photogrammetry Unit are also shown in the Video Display for additional information regarding the payload position, attitude, etc. The fine, coarse scales in Figure 17 illustrate the range graphically.

The SVS is designed on a fail/safe basis. System status and data integrity/validity checks are performed continuously. In case of errors, automatic recovery of a valid photogrammetric solution will be attempted. If the automatic recovery is not successful, the task will be terminated with annunciations on the SVS Display and Control panel regarding the cause of the termination as well as the recovery procedure to restart the task after the error has been removed. A flight experiment for the SVS is proposed for 1986 to demonstrate some of its capabilities and to evaluate some of its options for an operational system.

A possibility exists to link the SVS with a control loop so that an operation such as payload tracking and capturing can be done automatically. Furthermore, with a force sensor-accommodation implementation on the SRMS, the berthing task can be performed with more ease, particularly without concerns of high loads due to trunion binding, etc. The above two augmentations to the SRMS are feasible; and in fact, can be extended to other space applications such as Space Station Manipulators, Orbital Manoeuvring Vehicle docking system, etc.

Concluding Remarks

All payload deployments and retrievals by the Shuttle Remote Manipulator System have been successful and the Canadarm on-orbit performance has been verified by a series of flight tests [3]. In order to ensure low payload tip-off rates it has been recommended, based on flight data, that:

(a) End Effector be withdrawn gradually during payload release,

(b) Payload deployment be delayed when performed after an SRMS Brake Release or after a VRCS deadband tightening.

In terms of payload capture and retrieval, it has been demonstrated that a payload rotating at 0.1°/sec could be captured without difficulty and the loads induced in the arm due to payload capture/arm rigidization have been quite low in comparison with the SRMS design load limits. In the future, the on-orbit performance verification of the SRMS will continue when it is used to deploy and retrieve heavier and probably faster moving payloads. The retrieval of the 21528 lb LDEF in mission 51D is an example. In any case, the SRMS performance can be improved and the payload deployment/retrieval task can be performed with more ease when the SRMS is augmented with a force sensor-accommodation system and the Space Vision System.

Acknowledgements

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References

[1] Handlykken, M. and Turner T. "Control System Analysis and Synthesis For A Six Degree of Freedom Universal Force Reflecting Hand Controller" IEEE, CDC, 1980.

[2] Fogel, L. "Biotechnology, Concepts and Applications" Prentice -Hall, 1963.

[3] Ravindran R, Sachdev S.S., Aikenhead B. "The Shuttle Remote Manipulator System and Its Flight Tests" Proceedings of The Fourteenth International Symposium on Space Technology and Science, Tokyo, 1984.

TABLE 1

PAYLOADS THAT HAVE BEEN CAPTURED OR RELEASED BY THE SHUTTLE REMOTE MANIPULATOR SYSTEM

ACTIVITY	MISSION	PAYLOAD	PAYLOAD MASS (LBS)
Capture Inside Cargo Bay	STS-3	Plasma Diagnostics Package (PDP)	343.
	STS-4	Induced Environment Contamination Monitor (IECM)	816.
	STS-8	Payload Flight Test Article (PFTA)	7460.
Capture Outside Cargo Bay	51-A	Palapa (+ Stinger and Man Manoeuvring Unit)	2207.
Capture Inside Cargo Bay & Release	41-C	Long Duration Exposure Facility (LDEF)	21528.
	41-G	Earth Radiation Budget Satellite (ERBS)	5087.
Capture Outside Cargo Bay & Release	41-C	Solar Maximum Mission (SMM)	4956.
Capture Inside and Outside Cargo Bay & Release	STS-7	Shuttle Pallet Satellite (SPAS-01)	3172.

TABLE 2

DOWNLISTED RMS DATA

VARIABLE	INSTRUMENTATION	RESOLUTION	DOWNLISTED RATE
Joint Angle	Optical Encoder	$\pi/(2^{15})$ $\frac{\text{rad}}{\text{count}}$	12.5 Hz
Motor Rate	Inductosyn Tachometer	$45/(2^{9})$ $\frac{\text{rad}}{\text{sec}}/\text{count}$	12.5 Hz
Joint Torque	Strain Gauge	Varying	12.5 Hz
	(not available in STS7, 41C, 41G and 51A missions)	185.09 to 203.03 $\frac{\text{In-lbs}}{\text{count}}$ at shoulder 55.97 to 71.04 $\frac{\text{In-lbs}}{\text{count}}$ at wrist	
Capture/Release Flag	Microswitch, via GPC	—	1 Hz
Rigidization/Derigid-ization Flag	Microswitch, via GPC	—	1 Hz
Payload Linear Acceleration	Accelerometer (STS7 only)	.0000985275 $\frac{\text{ft}}{\text{sec}^2}/\text{count}$	20 Hz
Payload Angular Rate	Gyro (STS7 only)	.0001221896 $\frac{\text{deg}}{\text{sec}}/\text{count}$	20 Hz

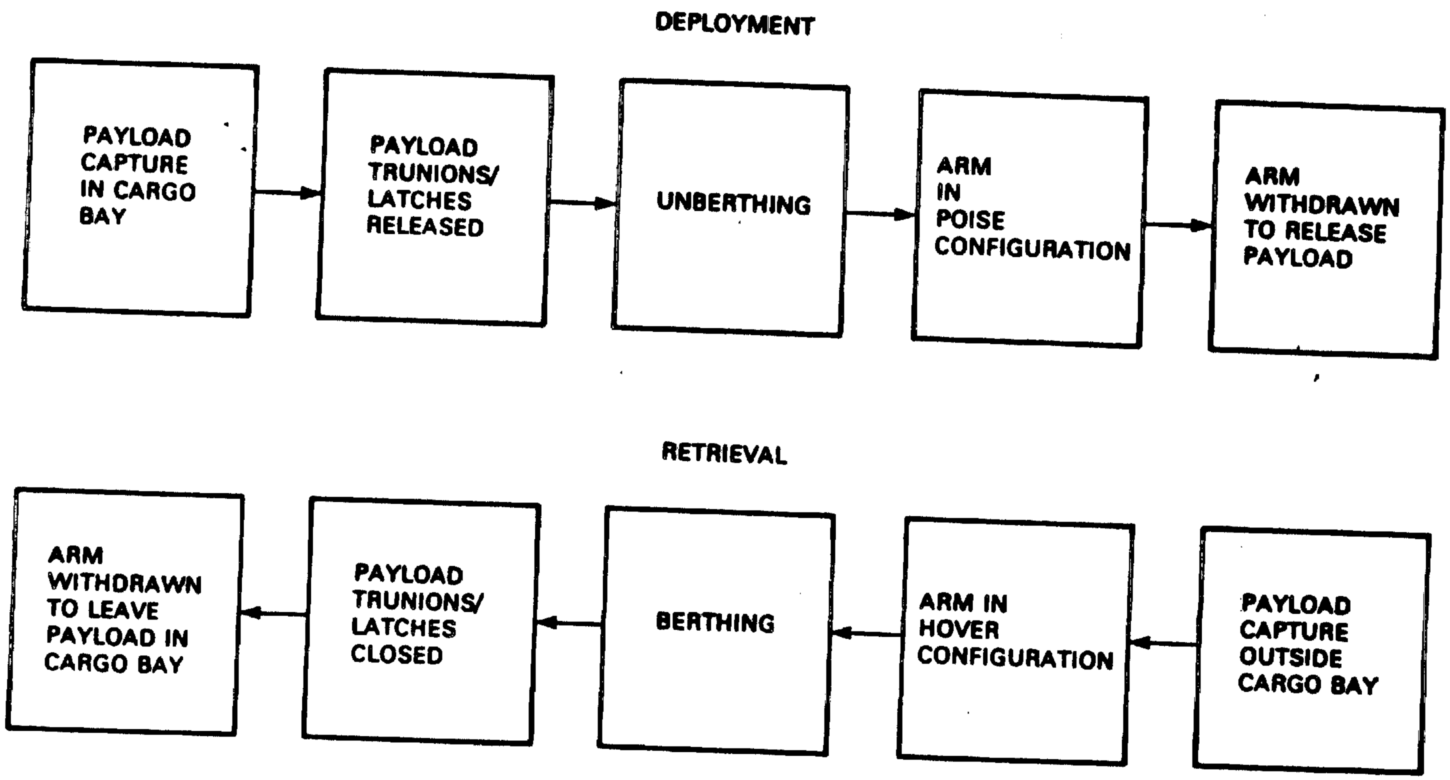


FIGURE 1 PAYLOAD DEPLOYMENT AND RETRIEVAL SCENARIOS

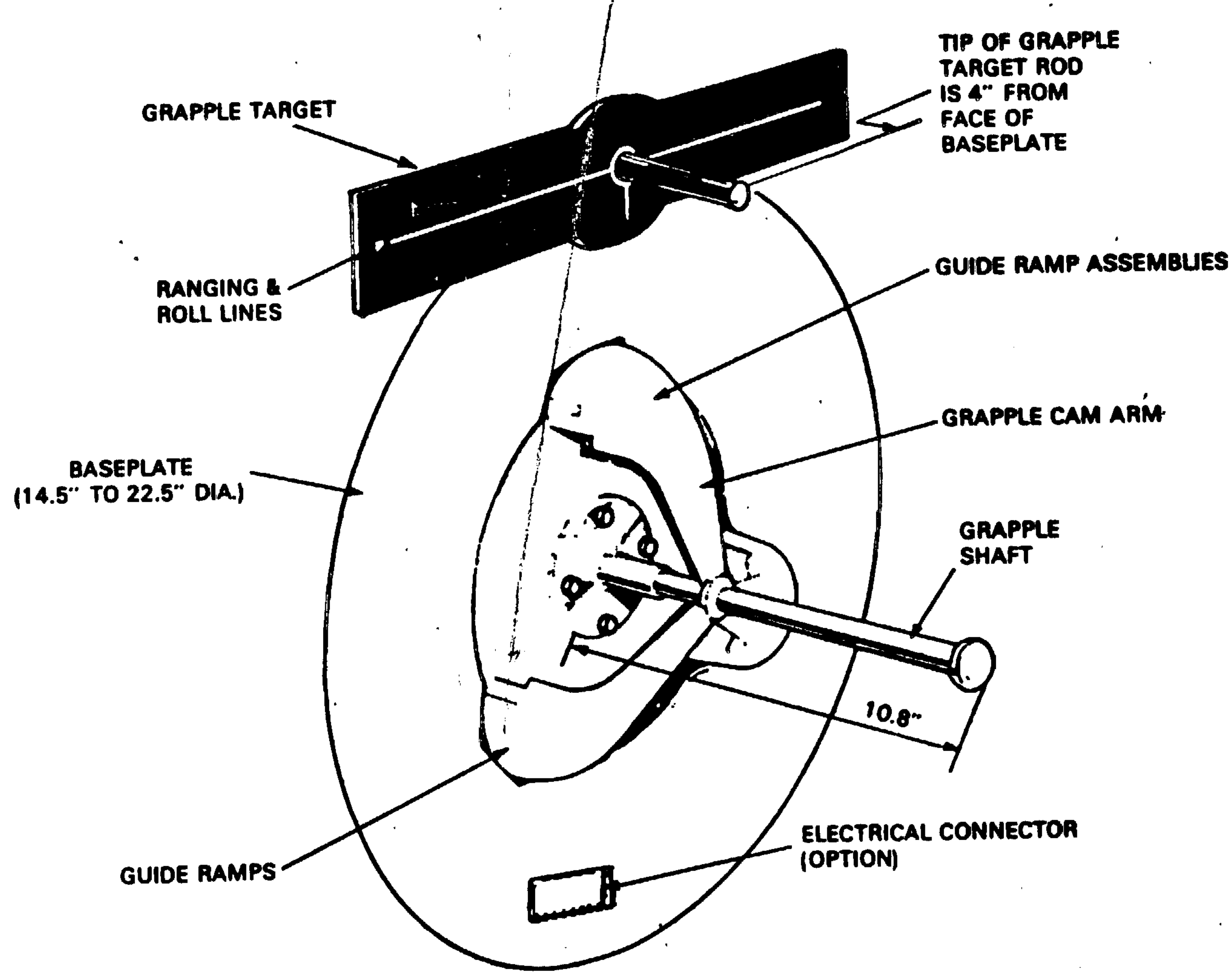


FIGURE 2 GRAPPLE FIXTURE WITH GRAPPLE TARGET

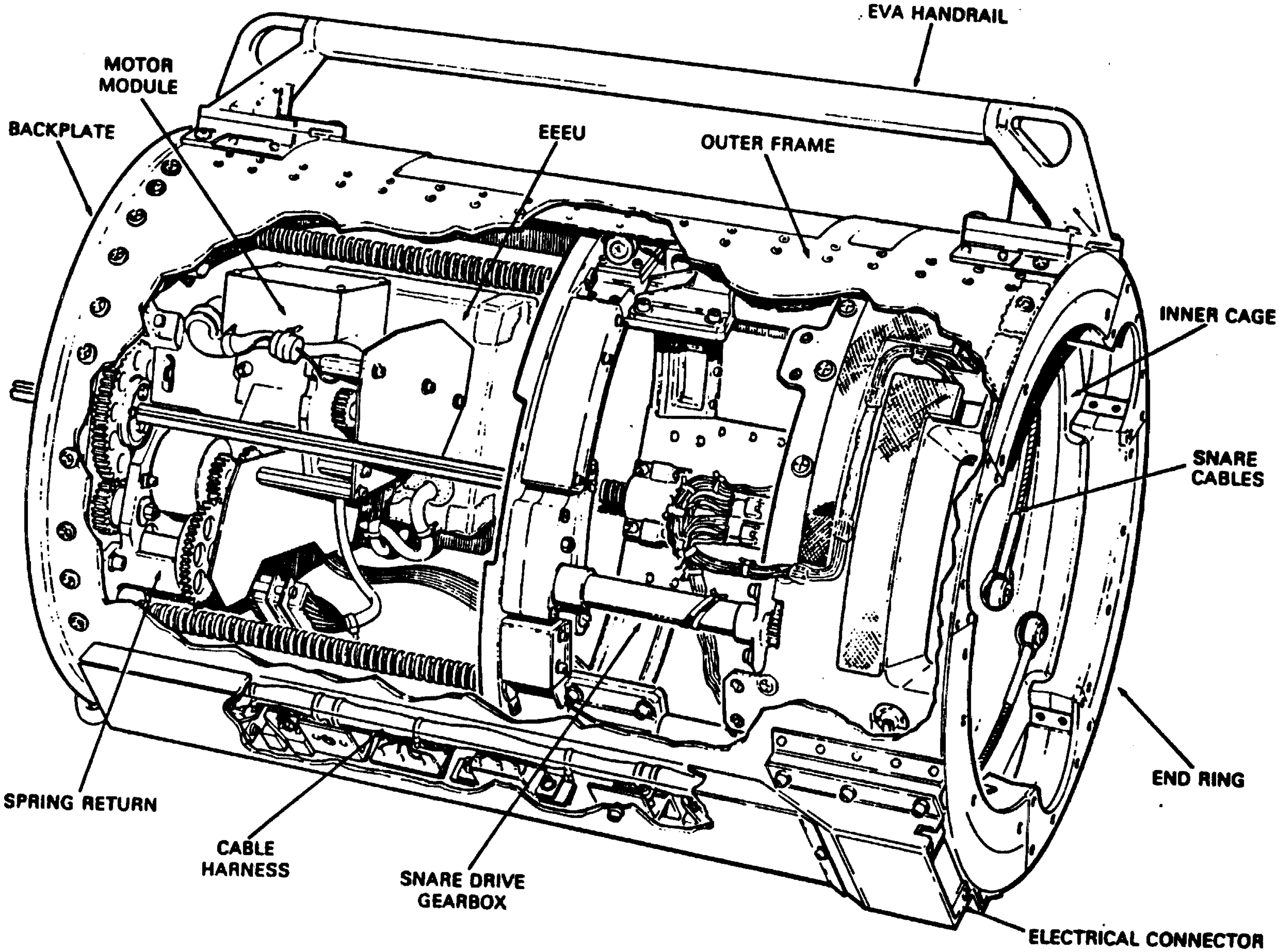


FIGURE 3 SRMS END EFFECTOR

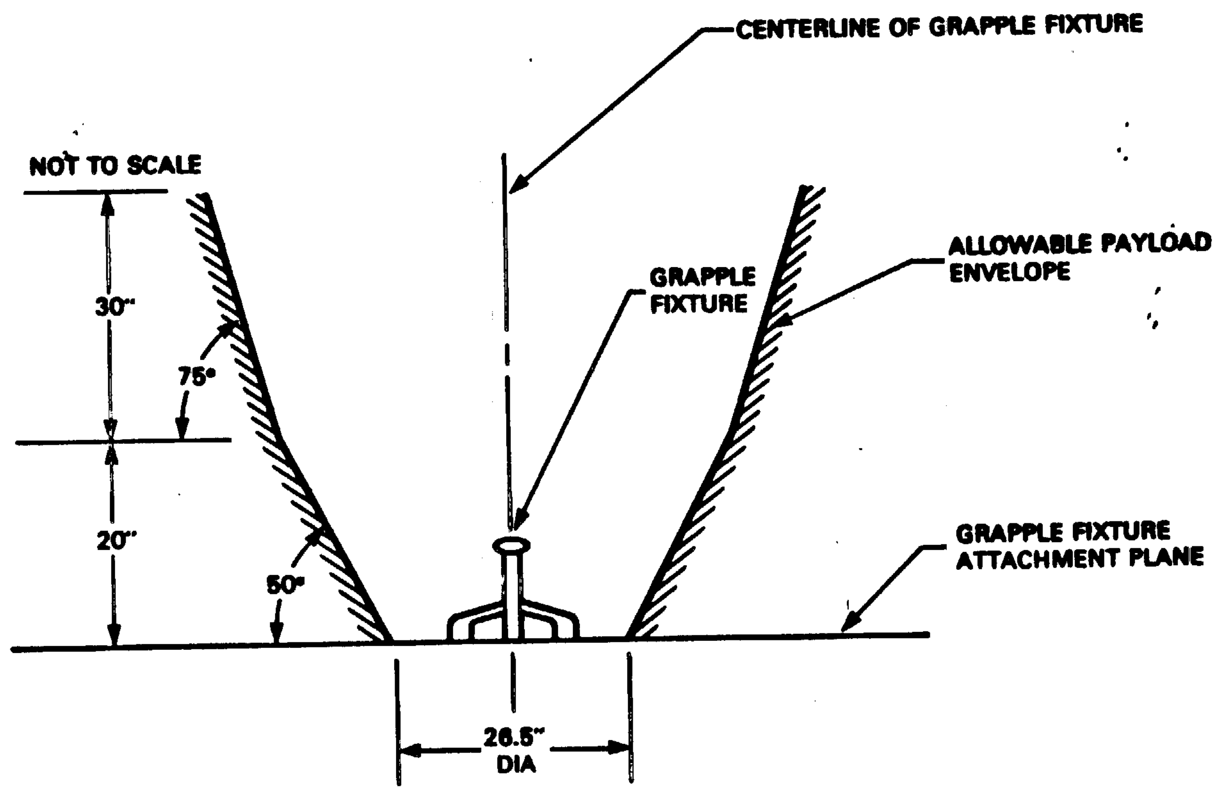


FIGURE 4 PAYLOAD CAPTURE CLEARANCE ENVELOPE

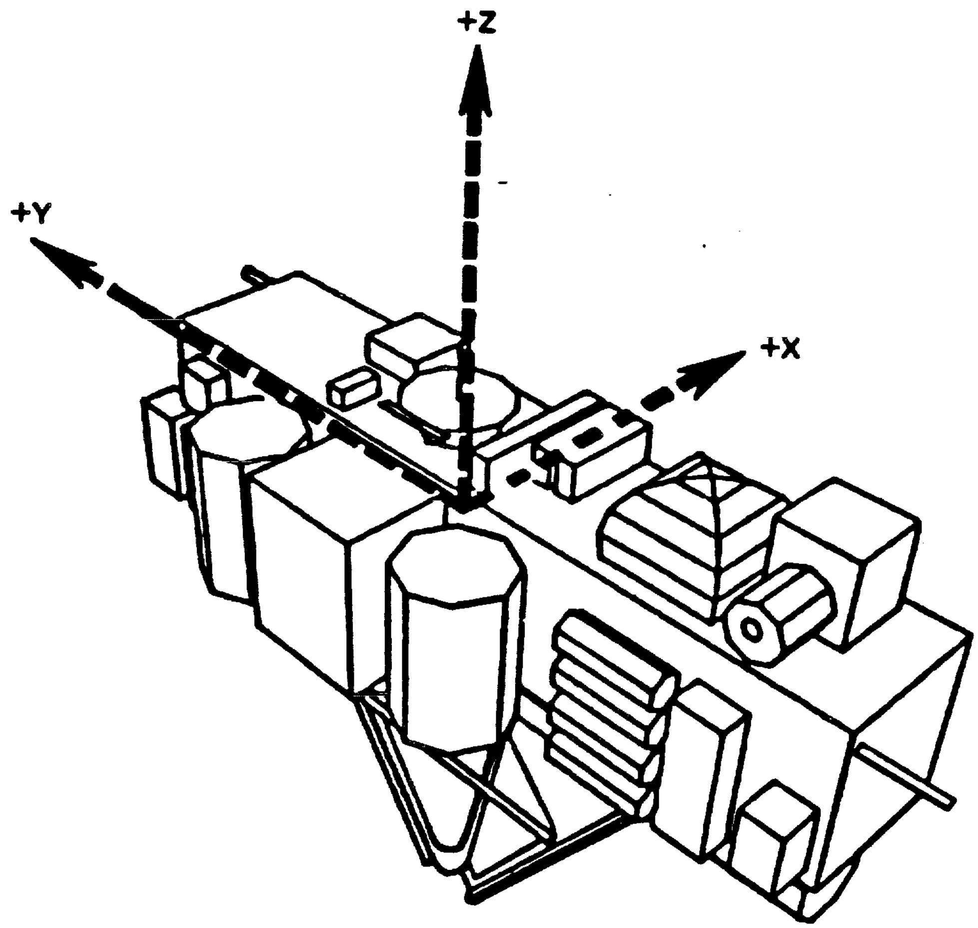


FIGURE 5 SPAS-01 AND ITS PAYLOAD AXIS SYSTEM

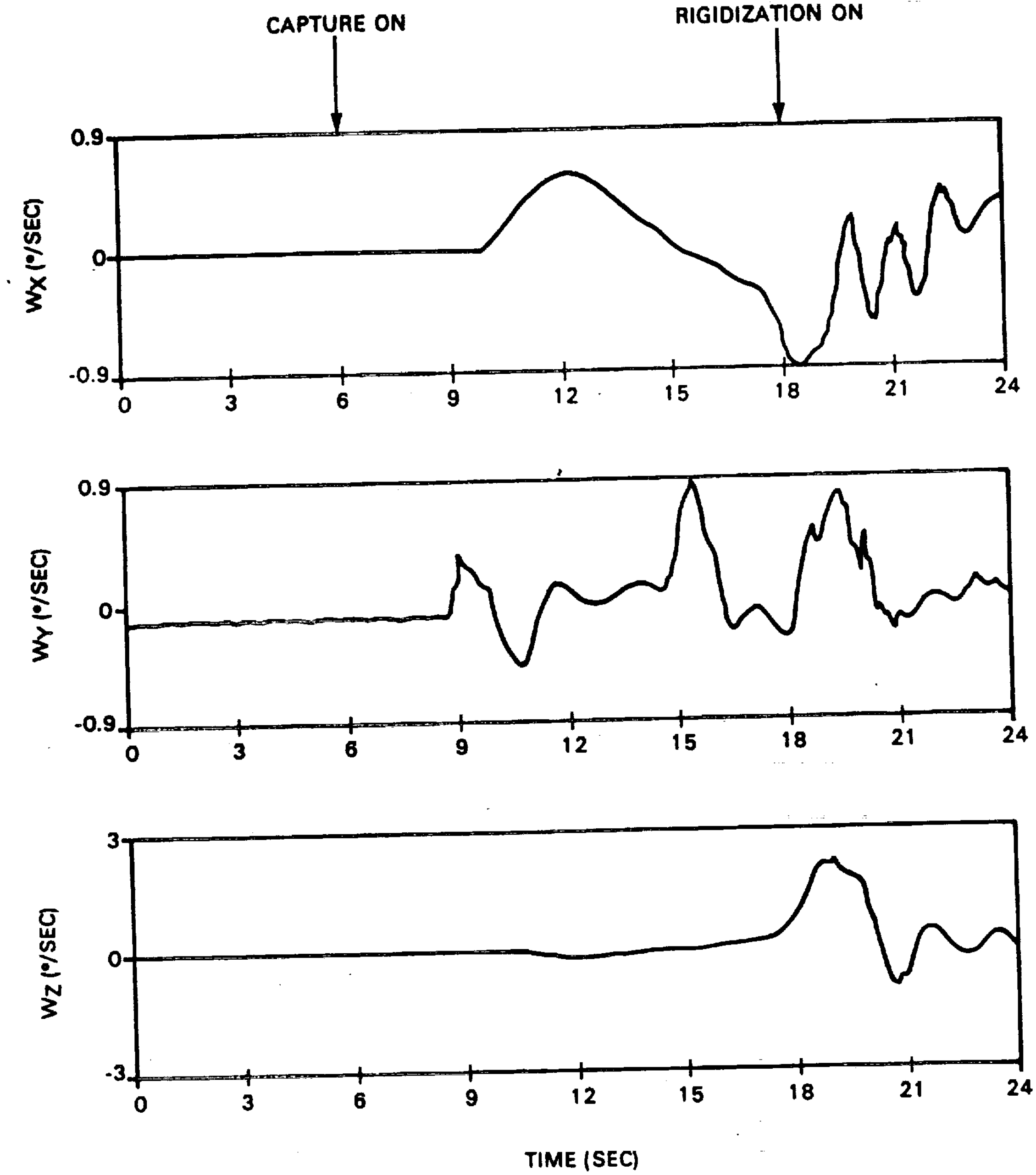


FIGURE 6 SPAS-01 BODY RATES DURING ITS CAPTURE AT 173:12:33:18 GMT

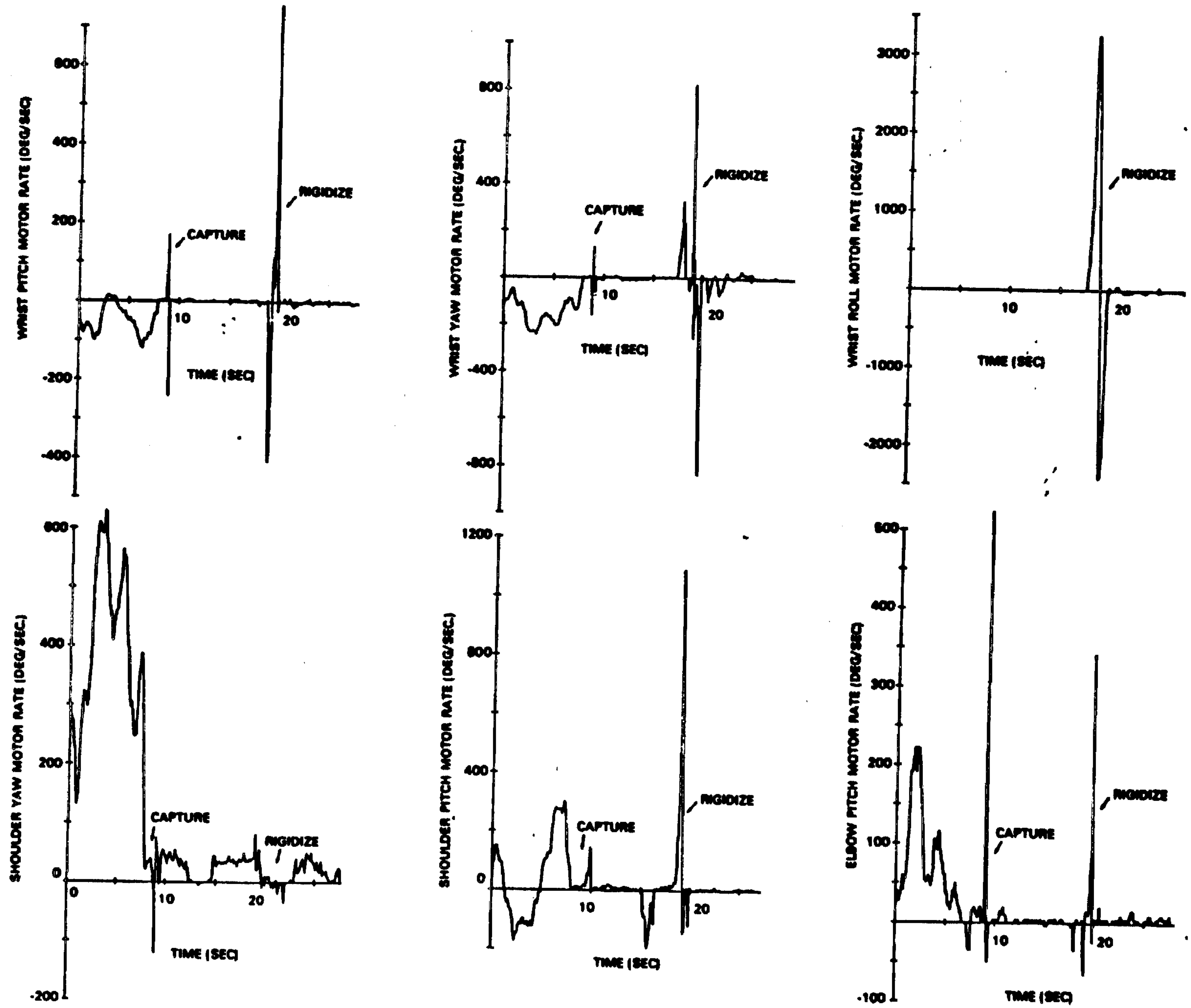


FIGURE 7 MOTOR RATES DURING CAPTURE/RIGIDIZATION OF ROTATING SPAS-01

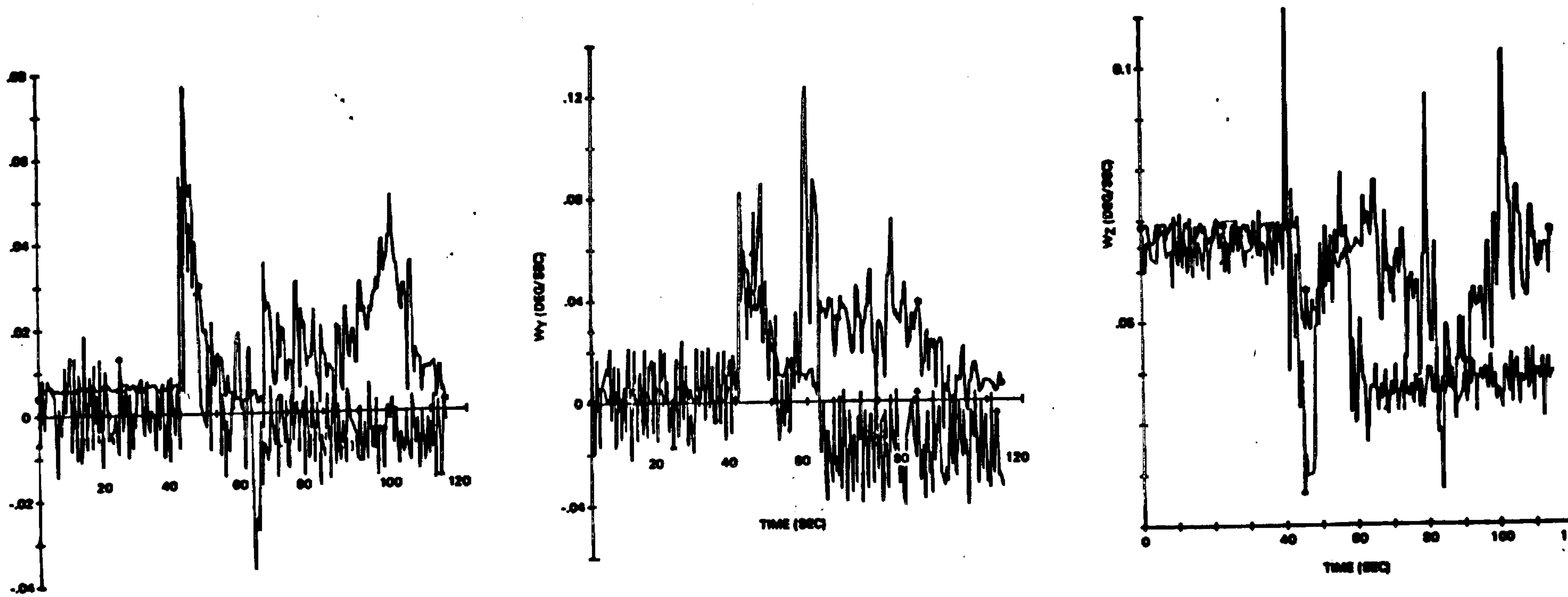


FIGURE 8 SPAS-01 ANGULAR RATE BEFORE AND AFTER RELEASE

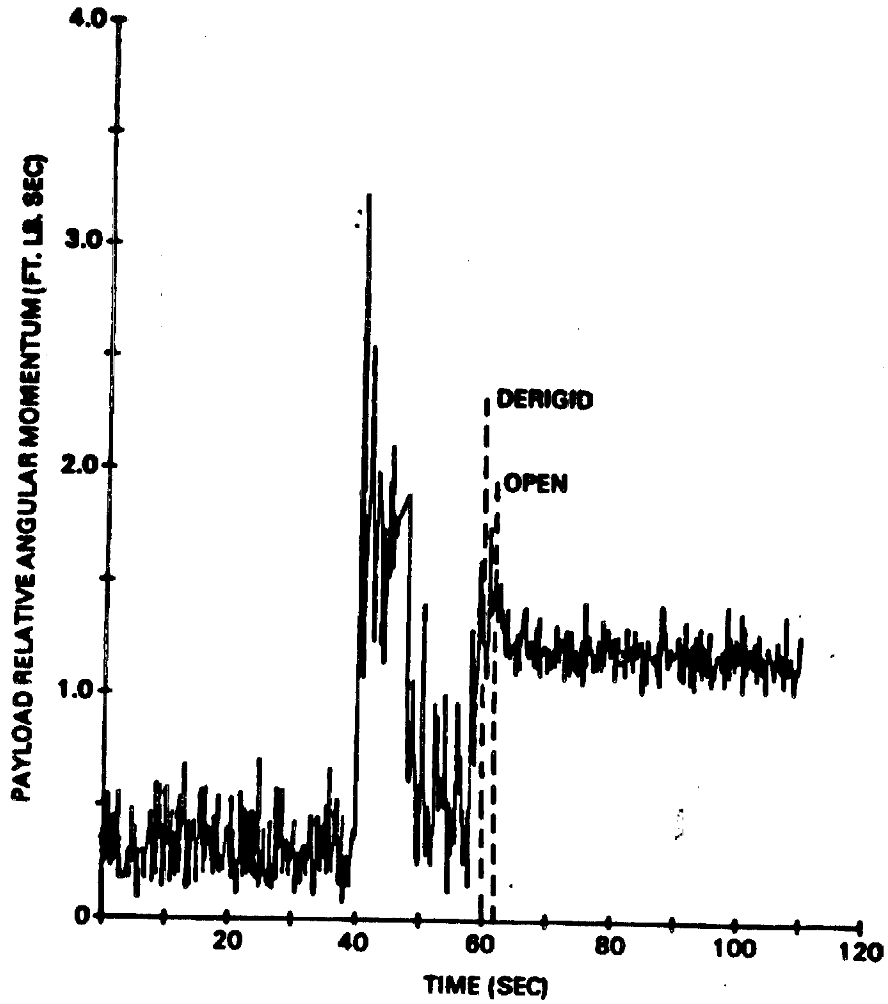


FIGURE 9 PAYLOAD RELATIVE ANGULAR MOMENTUM BASED ON SPAS-01 GYRO DATA

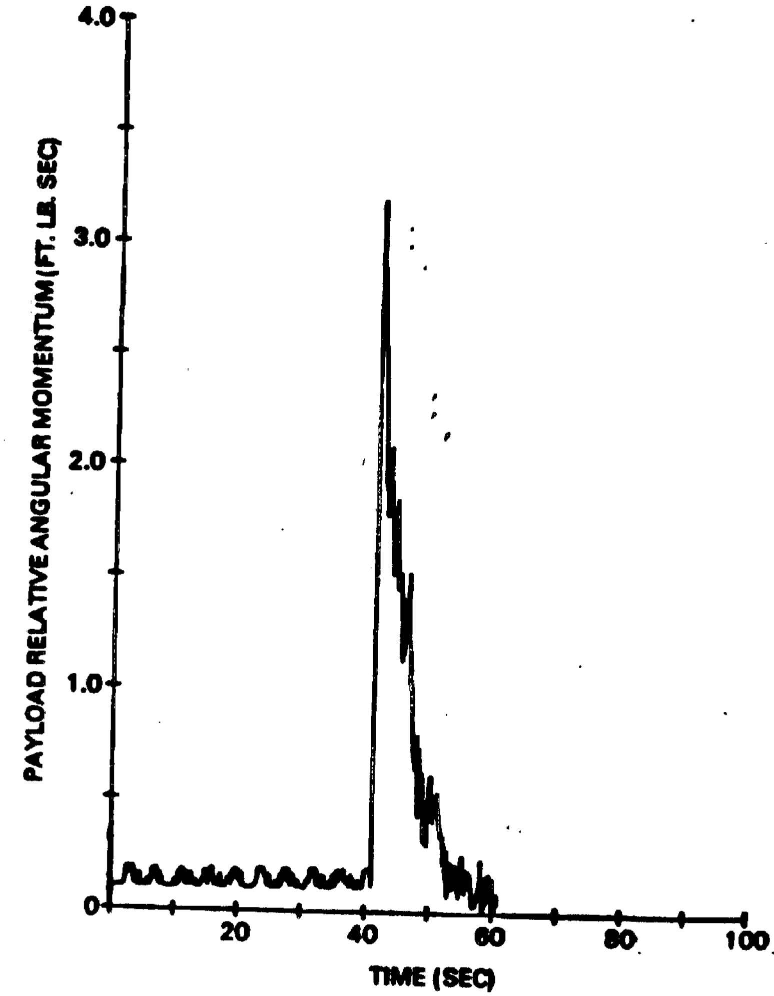


FIGURE 10 PAYLOAD RELATIVE ANGULAR MOMENTUM BASED ON SRMS - ESTIMATED END EFFECTOR RATE

ORIGINAL FOR

Page 5A-47 (Figure 11)

NOT AVAILABLE

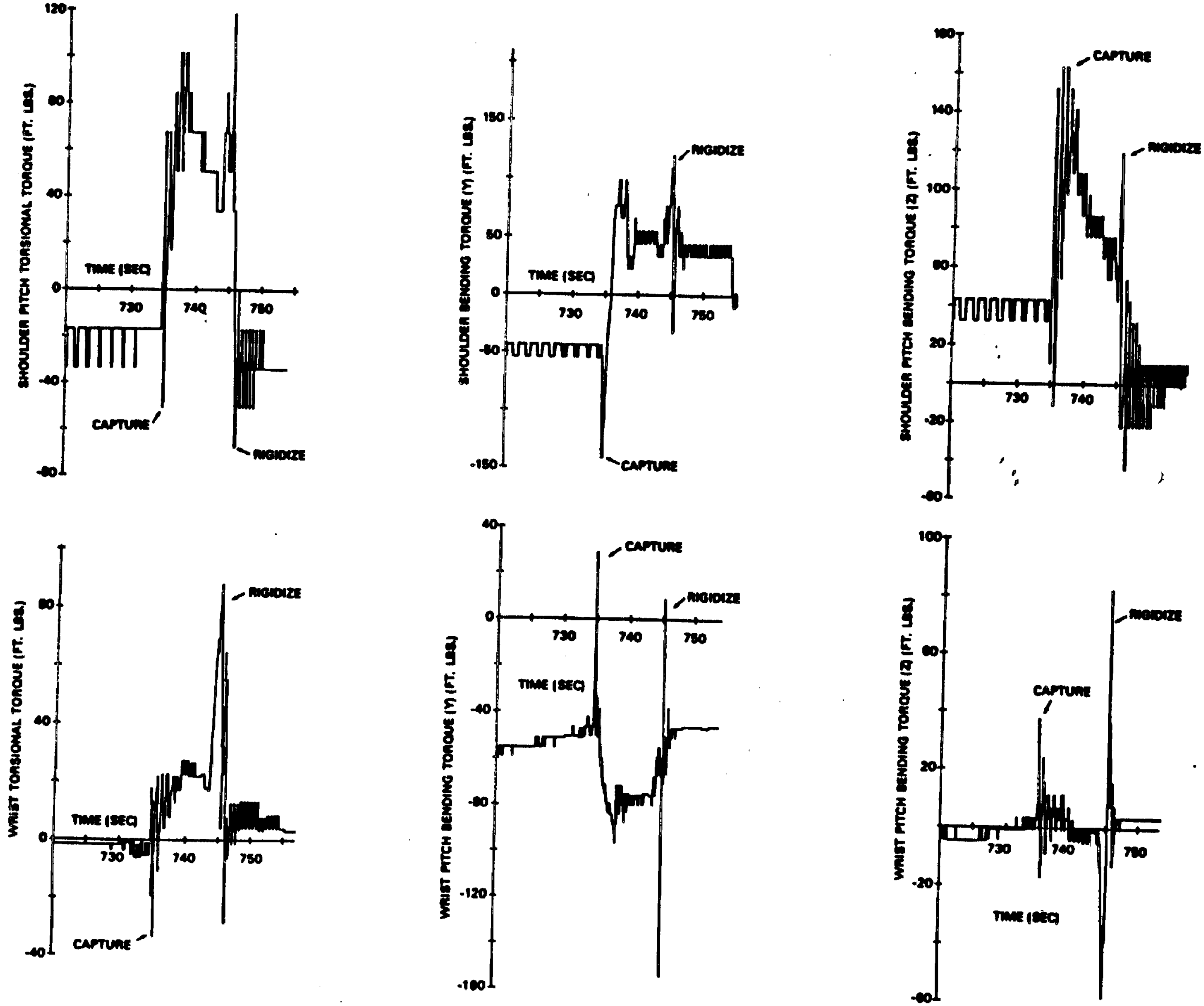


FIGURE 12 SHOULDER AND WRIST LOADS DURING CAPTURE AND RIGIDIZATION

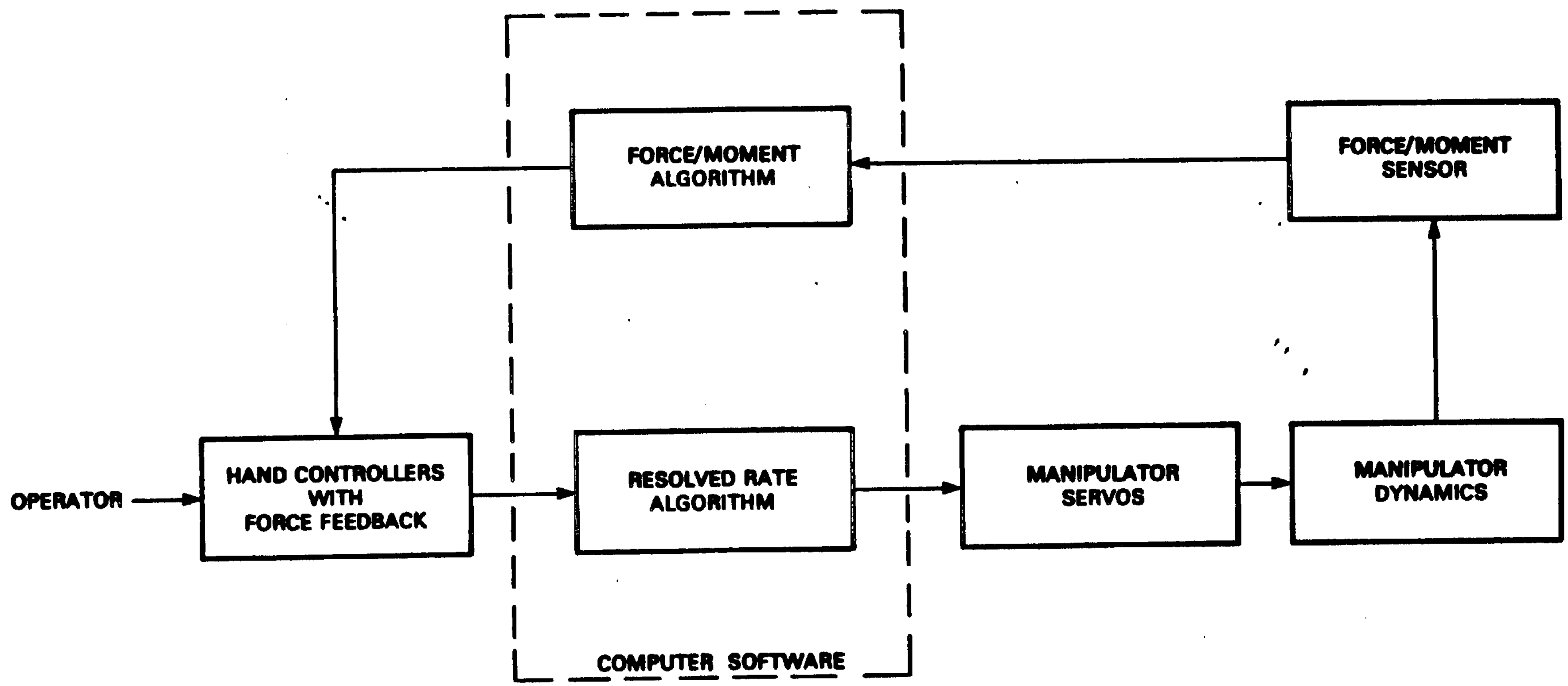


FIGURE 13 FORCE FEEDBACK HAND CONTROLLERS AND RESOLVED RATE ALGORITHM CONTROL SYSTEM

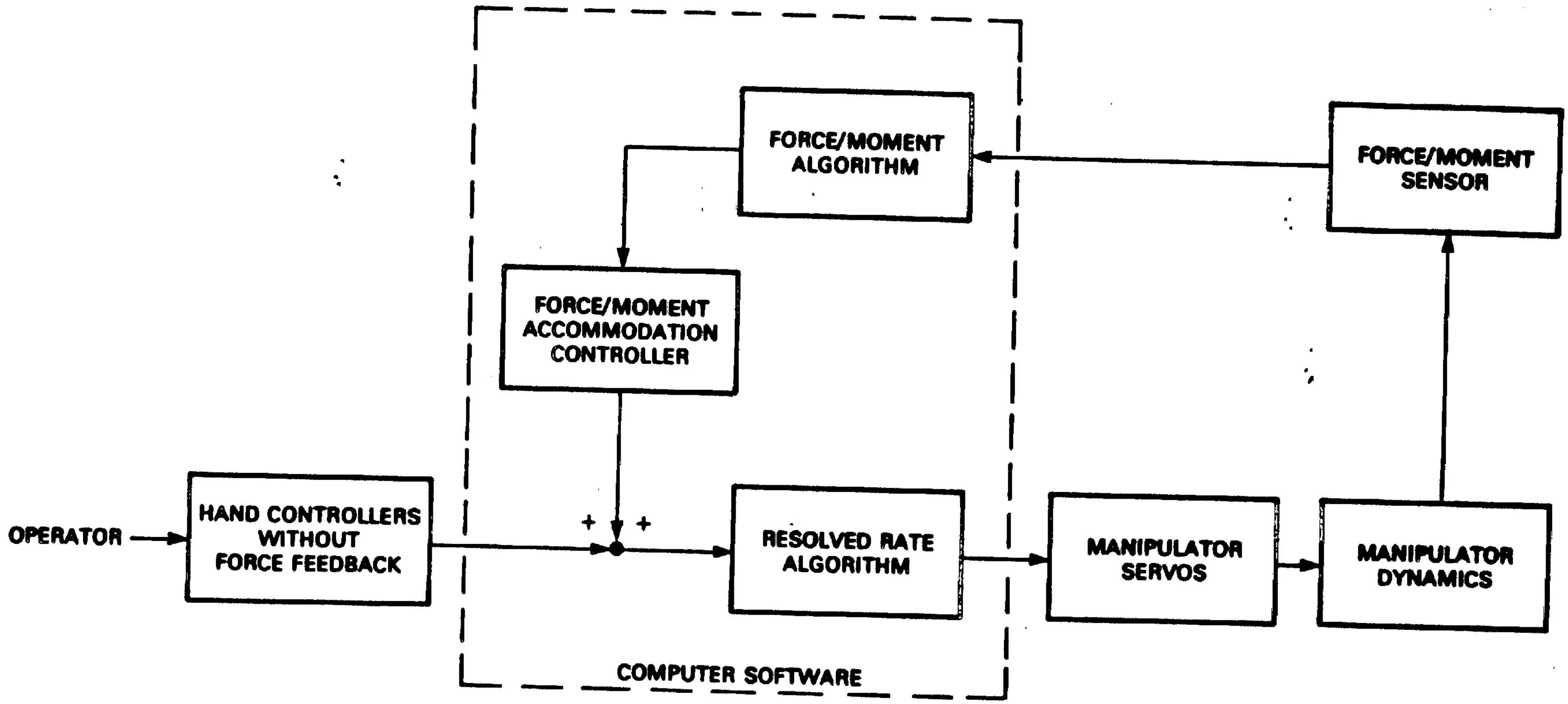


FIGURE 14 FORCE ACCOMMODATION AND RESOLVED RATE ALGORITHM CONTROL SYSTEM

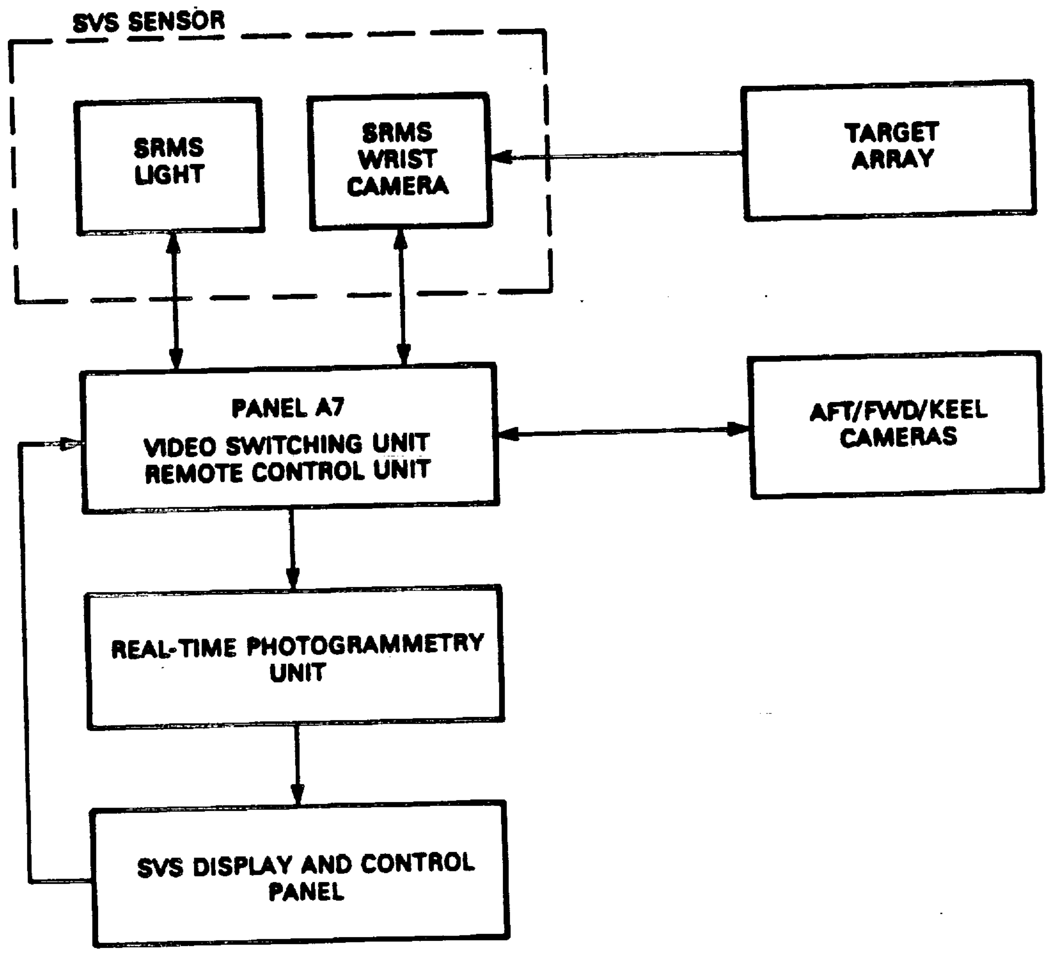
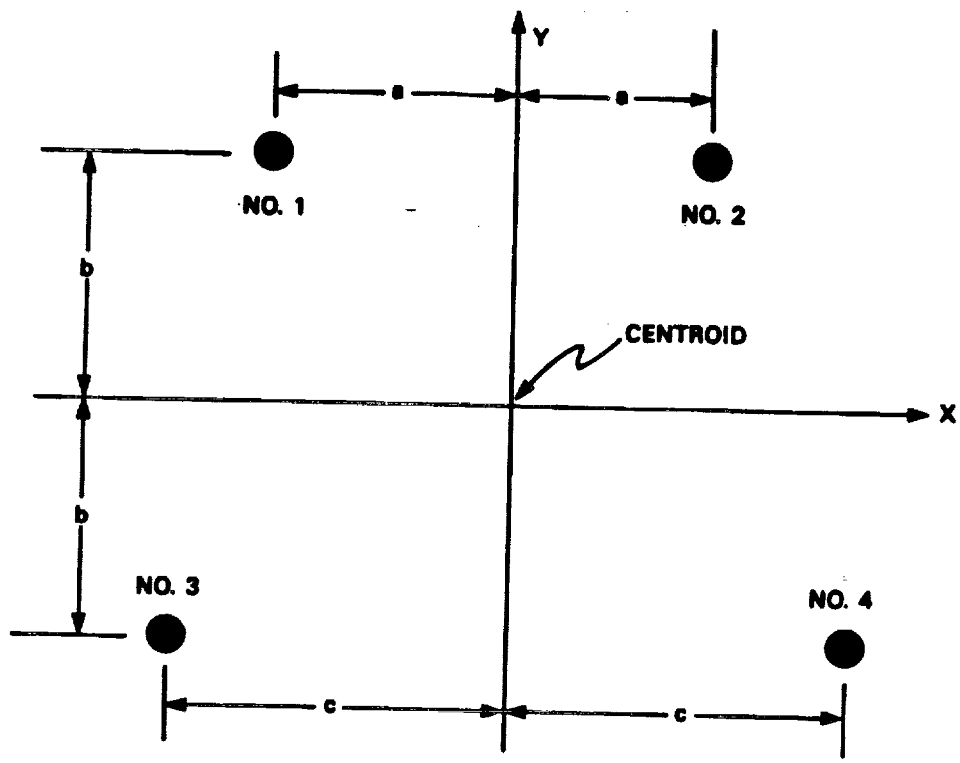


FIGURE 15 BLOCK DIAGRAM FOR THE SPACE VISION SYSTEM



WHITE DOTS ON BLACK BACKGROUND OR VICE VERSA

FIGURE 16 STANDARD TARGET ARRAY GEOMETRY

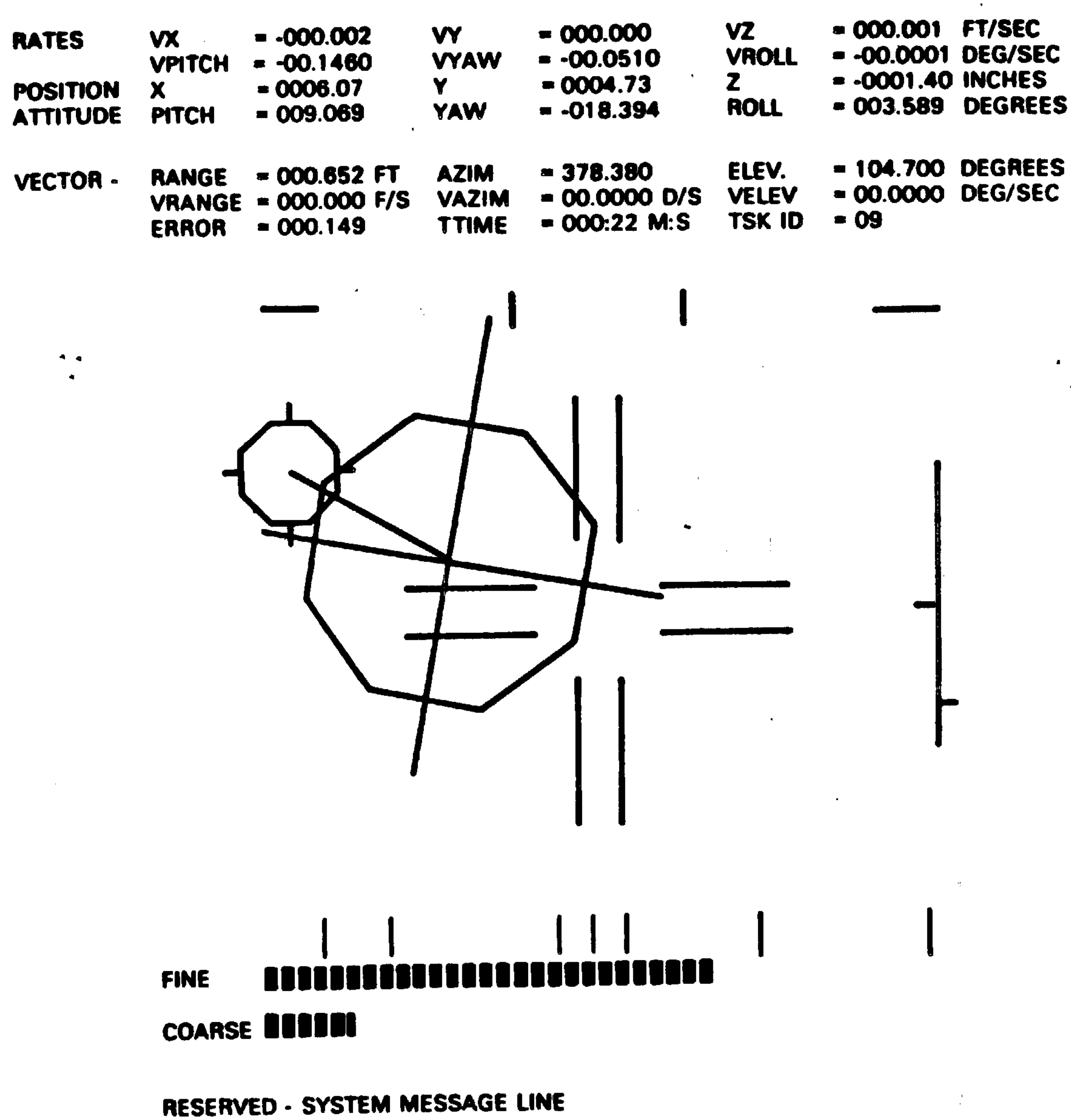


FIGURE 17 VIDEO GRAPHIC DISPLAY

5A-54

MECHANISMS AND MAN/MACHINE OPERATIONS

TRANSPORTATION - SPACE STATION INTERFACES

RENDEZVOUS AND PROXIMITY OPERATIONS WORKSHOP

JOHNSON SPACE CENTER

FEBRUARY 19-20, 1985

PRESENTOR: IAN O. MACCONOCHIE

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INTRODUCTION

Historically, many devices are utilized for transportation and processing around ground-based production facilities. These include conveyors, cranes, fork lift trucks, and, in recent years, robotic devices. These devices are all directed toward improving the capability and efficiency of the production and delivery process. In some ways, a Space Station facility (where propellants are transferred, payloads are assembled, and manufacturing processes conducted) is similar.

In space, however, the structural requirements in a zero g environment are several orders of magnitude lower. Also, disturbances to (and contamination of) the facility must be kept to a minimum, and man's time and electrical power are premium resources. All of these factors require that new thinking be applied to the old systems, and in some instances, entirely new concepts must be developed.

Numerous robotic devices are currently used in ground-based manufacturing. A robotic device designed for movement of cargo in space exists in the form of the remote manipulator system (RMS) on the Space Shuttle Orbiter. Numerous robotic devices for proposed Space Station applications exist in concept only. A mobile manipulator that moves up and down the keel structure has been shown in preliminary Space Station designs.

The need exists, however, for the identification of devices for the transport of space vehicles and cargo on and near the Space Station. Requirements may dictate the use of relatively rapid systems for routine transfer of cargo up and down the keel for an operational Space Station.

Many economic and other (design) considerations will dictate the final selection of mechanical devices used in proximity operations at the Space Station. The Shuttle Orbiter with its RMS will undoubtedly be utilized to its fullest extent. The concepts presented herein may merely be of derivative value in the development of other concepts.

INTRODUCTION

- O HISTORICALLY, MANY DEVICES ARE USED AROUND GROUND-BASED PROCESSING FACILITIES TO MOVE CARGO INTO, OUT OF, AND THROUGHOUT THE FACILITY
- O ON-ORBIT, FUNCTIONALLY SIMILAR DEVICES WILL BE NEEDED TO MOVE CARGO IN PROXIMITY OF THE SPACE STATION
- O ALTHOUGH SIMILAR IN PURPOSE, THE SPACE MECHANISMS
  - WILL EXPERIENCE LOADS SEVERAL ORDERS OF MAGNITUDE LOWER
  - MUST PERFORM THEIR TASKS EXPEDITIOUSLY BECAUSE OF THE PREMIUM ON ASTRONAUT'S TIME AND ELECTRICAL POWER

OBJECTIVES

The emphasis of this paper is on mechanisms which would be useful for the transfer and manipulation of various masses in the vicinity of (or on) a Space Station. These transfers of mass are categorized as follows:

1) Mass transfers involved in the arrivals or departures of various vehicles including the Shuttle, Orbital Maneuver Vehicles (OMV'S), and Orbital Transfer Vehicles (OTV'S)

2) Point-to-point mass transfer of a non-routine nature around the Space Station. For example, that involved in the assembly of Space Station structure.

3) Routine transfer of cargo and spacecraft around the Space Station such as the mating and processing of OMV'S, OTV'S, propellants, and payloads.

The overall objective of this paper is to identify conceptual mechanisms that perform these mass transfers with minimum impact on resources of time, personnel, and power with low levels of contamination and upsetting forces.

OBJECTIVES

- O OVERALL: TO IDENTIFY CONCEPTUAL MECHANISMS FOR MASS TRANSFER ON, AND IN PROXIMITY OF, A SPA STATION

- O SPECIFIC: IDENTIFY MECHANISMS DESIGNED TO ENHANCE PROCESSING AND TRANSPORTATION SYSTEM OPERATIONS WHILE MINIMIZING DISTURBANCES TO, AND CONTAMINATION OF, THE STATION

  CONCEPTUAL MECHANISMS FOR:
  - SPACE STATION ARRIVALS AND DEPARTURES
  - FOR POINT-TO-POINT MASS TRANSFER AROUND A SPACE STATION
  - ROUTINE CARGO TRANSFER UP AND DOWN A SPACE STATION KEEL

- O ULTIMATE GOAL: SAFE, TIMELY ARRIVALS AND DEPARTURES AT THE STATION AND IMPROVED OPERATIONAL EFFICIENCY ON THE STATION

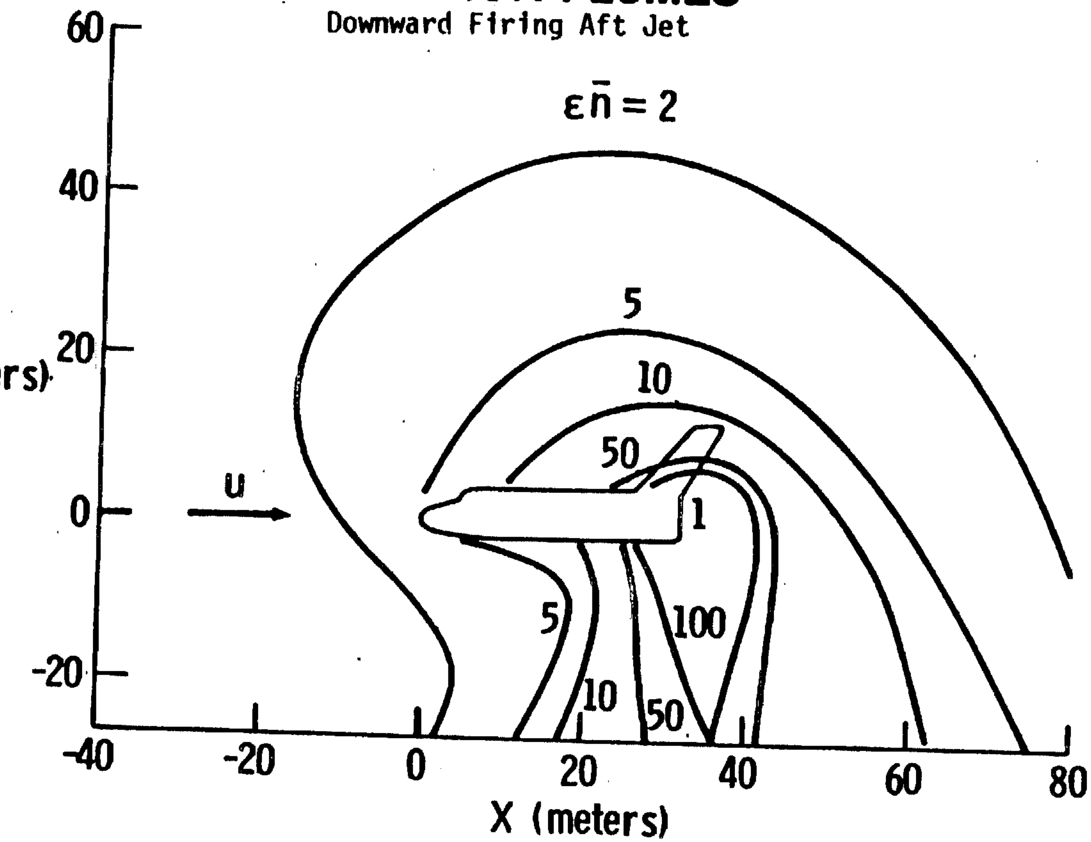
VEHICLE REACTION CONTROL SYSTEM EXPANSION PLUMES

The exact effects of the reaction control system (RCS) plumes from the incoming vehicles on the Space Station is difficult to quantify. The contour map shows plume densities for a downward firing vernier jet in the aft RCS module on the Shuttle Orbiter. Nine constituents are included in the calculations: three are natural constituents, three the result of outgasing from the Shuttle, and three from Shuttle engines. The summation of the densities of these constituents is ratioed to a free-stream density and is shown on the accompanying plot of contours. Monte Carlo calculations of the flow field in the vicinity of the Shuttle RCS engines are presently being made and additional parameters will be available in the near future.

A berthing device which captures the incoming vehicles at approximately 200 ft, would place the station at a position well beyond the density contour of 2 for the downward firing rearward jet shown. An issue in the design of any capture and launch mechanism is the determination of its length and size versus the possible contamination and disturbance to the station from arriving and departing vehicles. The use of a long berthing beam would tend to minimize contamination and jet impulsive disturbances to the station.

VEHICLE REACTION CONTROL SYSTEM EXPANSION PLUMES

Downward Firing Aft Jet



Source: L. T. Melfi

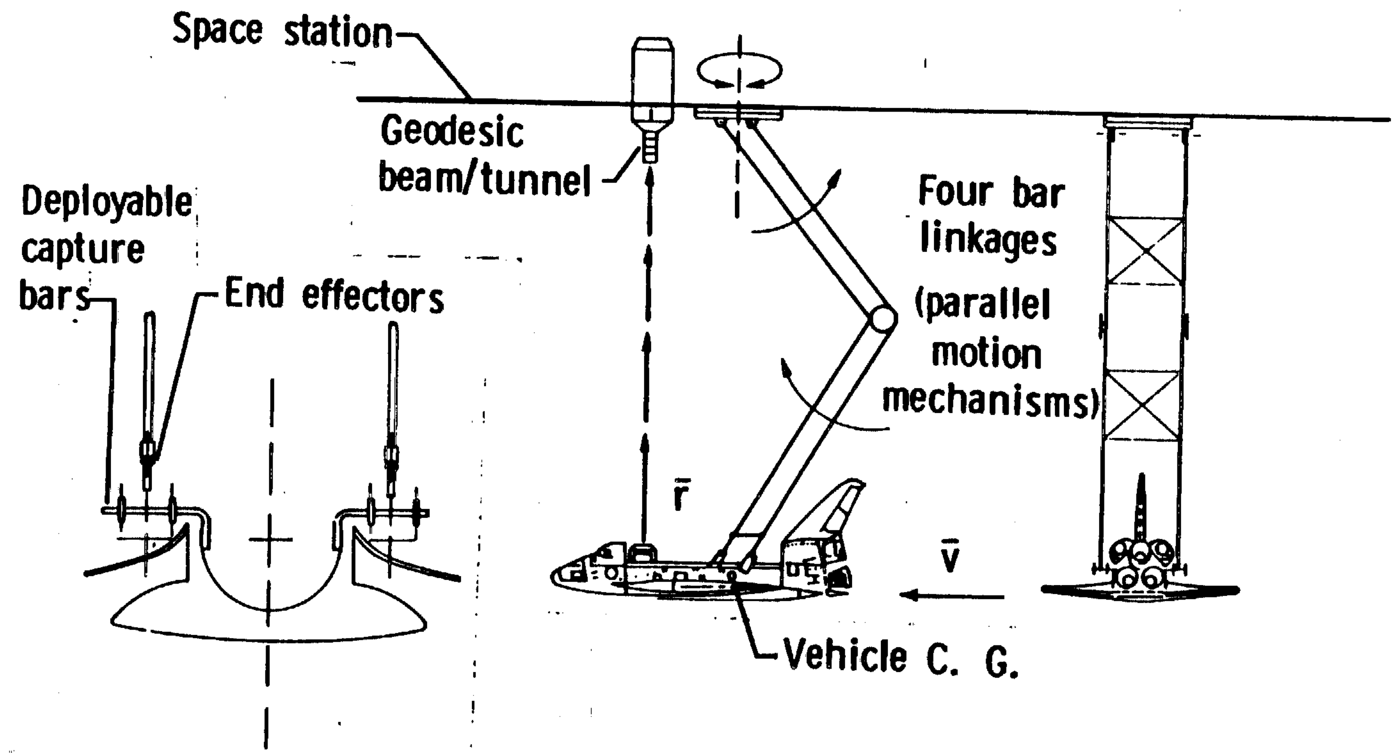
CAPTURE-BERTHING-DOCKING AND LAUNCH SYSTEM

For capture and berthing of incoming vehicles, a system consisting of two sets of parallel-motion four-bar linkages is proposed. By programming the angular displacement of each motor at linkage pivots, the incoming vehicle can be driven linearly to minimize torquing action on the station and possible saturation of the control moment gyro (CMG) system. (Note: Any acceleration motion of the berthed vehicle on the mechanism, other than along a radius vector to the Space Station c.g., would cause a torquing action on the station. A purely rotary action in the form of a trapeze was analysed for berthing and docking the Shuttle, but the torquing impulse easily saturated the 8 CMG'S assumed unless lapsed times in excess of 2 hours were used).

For a 500 lb-sec linear impulse limit on the station, a 235,000 lb Shuttle Orbiter can be moved 200 ft in 0.84 hours using the four-bar linkage system. Initially, a 10-lb force is applied for 50 seconds followed by a coast period, during which time just enough power is supplied to overcome friction. Just prior to docking, an equal deceleration impulse is applied.

Vehicles are powered down and safed prior to capture by actively controlled end effectors on the actively controlled four-bar mechanism. The same mechanism can also be used for the launching (as well as for capture) of satellites and orbital maneuvering, orbital transfer, and other vehicles. Each satellite or vehicle would be equipped to interact with the four end effectors located at the four corners of the four-bar linkage capture/launching mechanism. These capture bars, with end flanges to prevent lateral movement of end effectors, could be fabricated from lightweight composites.

CAPTURE-BERTHING-DOCKING AND LAUNCH SYSTEM



CAPTURE-BERTHING-DOCKING MECHANISM: OPERATIONAL PHASES

For the mechanism just described, the incoming vehicle will probably arrive with small $\bar{r}$ and $\bar{V}$ velocity residuals. The mechanism deploys and actively tracks the vehicle, gradually reducing relative velocities between end effectors and capture bars on the vehicle. When the relative velocities have been reduced to small values, the end effectors engage the capture bars. At engagement, motors and magnetic clutches at joints are de-energized (i.e. rendered pliant). Because the mass of the end effectors will be relatively small and the capture bars elastic, moderate relative velocities can be accommodated. The only consequence is a small impulse of short duration from the impact on the mechanism.

While the vehicle is attached to the mechanism, augmentation impulses are applied, either to slow down or speed up the incoming vehicle, until the required berthing point or docking station is reached. A final braking impulse is applied just before docking. In the normal operational mode, the momentum of the incoming vehicle at capture should not exceed the design allowable. If the momentum of the incoming vehicle does exceed the design allowable, the impulse dump to the station would be exceeded (either linear or angular impulse) unless countermeasures are taken such as operation of the RCS system on the vehicle or Space Station while the vehicle is on the mechanism. As an alternative, the vehicle berthing could be aborted by the release of the end effectors. As an additional safety feature, the mechanism could be equipped with strain guages, or optical (alignment) sensors, to insure that the allowable deflections (torsional and at right angles to pivots) are not being exceeded.

CAPTURE-BERTHING-DOCKING MECHANISM:OPERATIONAL PHASES

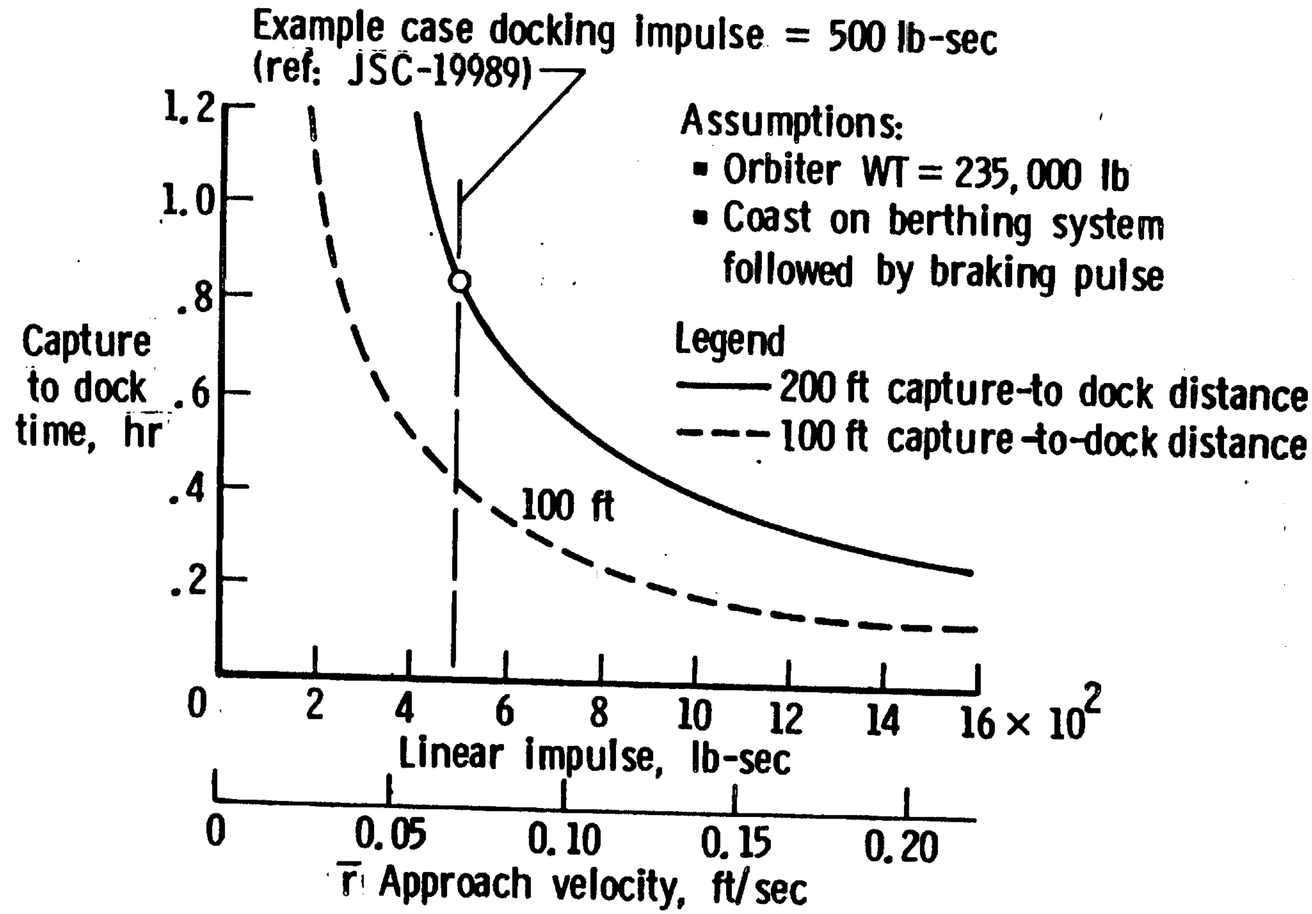
- O CAPTURE
  - VEHICLE ARRIVES WITH $\bar{R}$ AND $\bar{V}$ VELOCITIES
  - MECHANISM DEPLOYS AND ACTIVELY TRACKS VEHICLE MATCHING VEHICLE VELOCITY
  - WHEN $\bar{R}$ AND $\bar{V}$ VELOCITIES ARE SMALL, END EFFECTORS ENGAGE CAPTURE BARS
  - AT ENGAGEMENT, MOTORS AND MAGNETIC CLUTCHES AT MECHANISM JOINTS ARE DE-ENERGIZED (I.E. RENDERED PLIANT)
- O BERTH
  - VEHICLE COASTS ON MECHANISM (AUGMENTATION IMPULSES FROM MOTORS APPLIED AS REQUIRED)
  - AS BERTHING POSITION APPROACHES, BRAKING IMPULSE IS APPLIED
- O DOCK
  - DOCKING MECHANISM DEPLOYS TO ACTIVELY LATCH VEHICLE TO SPACE STATION

CAPTURE-TO-DOCK TIME VERSUS IMPULSE AND $\bar{r}$ VELOCITY

An $\bar{r}$ relative velocity of an arriving vehicle will result in a linear impulse applied to the station (assuming $\bar{r}$ velocity vector and Space Station c.g. are a co-linear). In the analysis, the mechanism is assumed to acquire the relative velocity of the incoming vehicle either by active control, or by impact between capture bars and the four end effectors, (This statement also applies to the $\bar{V}$ approach case). In the example case (see figure) the product of the mass of a 235,000 lb Orbiter (7300 slugs) and a velocity of 0.0685 ft/sec lb-sec equals 500 lb-sec. For this exmple, capture-to-docking time is 0.84 hr. for a 200 ft long mechanism deployment and is 0.42 hrs for a 100 ft long deployment.

Since impulse equals momentum change, the arrival velocity of lighter vehicles can vary inversely with mass. For example, if the weight of the arriving vehicle is only 23,500 lb (as opposed to 235,000 lb for a Orbiter) then $\bar{r}$ velocities permissible will be ten times that for the Orbiter or 0.685 ft/sec versus 0.0685 ft/sec. Docking times are correspondingly shorter or one tenth that for the Orbiter.

CAPTURE-TO-DOCK LAPSED TIME vs IMPULSE AND $\bar{r}$ VELOCITY FOR FOUR BAR LINKAGE SYSTEM



CAPTURE-TO-DOCK TIMES VERSUS IMPULSE AND $\overline{V}$ VELOCITY

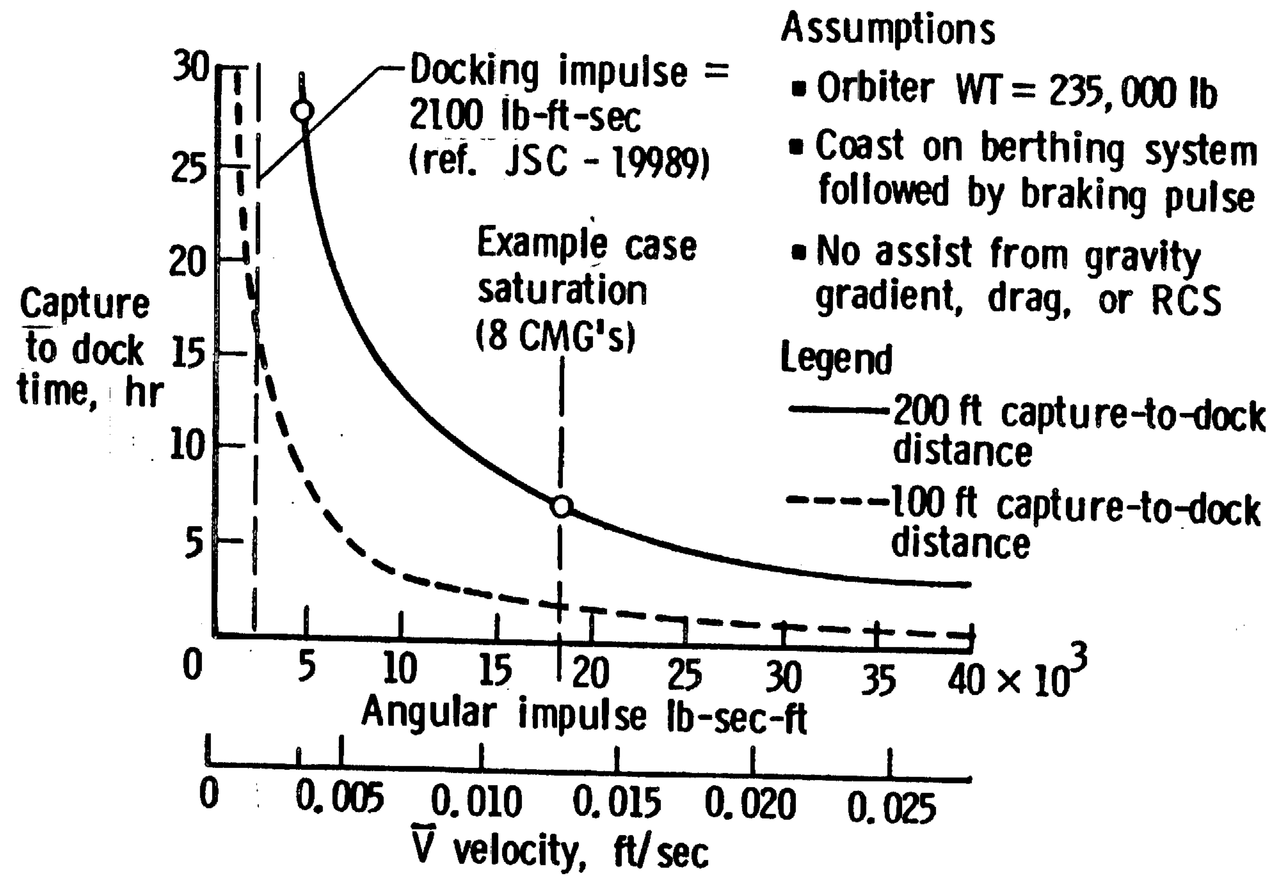
A $\overline{V}$ relative velocity of an arriving vehicle will result in impulsive torque on the Space Station. If the Space Station is equipped with 8 Control Moment Gyros (CMG's), the control system is saturated by the arrival of a 235,000 lb Orbiter on a 200 ft long mechanism at a $\overline{V}$ velocity of 0.0126 ft/sec. Effects of gravity grandient and drag are not included.

The time required for a 90° rotation to the station on a 200 ft long mechanism would require approximately 7 hrs. If the mechanism is 100 ft long from the pivot to the Shuttle c.g. and the same 8 CMG's are available, the rotation during coast based on allowable velocity would be 2 hrs. In this mode, the tangential velocity of the Orbiter on the four-bar linkage during the coast period is the arrival velocity. When the magnetic clutches are energized, the relative motion between the Space Station and Orbiter is brought to zero as the momentum exchange takes place between Orbiter and the Space Station just prior to docking.

Clearly, the permissible $\overline{V}$ approach velocities are too small for the assumption of 8 CMG's and the large mass of the Orbiter. By operating the Orbiter RCS jets while it is on the mechanism, the impulsive torque of the incoming Orbiter could be counteracted and higher $\overline{V}$ velocities made possible. This would, however, partially defeat the purpose of a long mechanical arm, or tower, for capture, berthing, and docking inasmuch as the additional usage of jets would tend to contaminate the Space Station even though the vehicle-to-space station distance is 200 ft.

In comparison to the Shuttle Orbiter, a 23,500 lb space vehicle could be rotated from a capture position at a 200 ft radius up to the Space Station in one tenth the lapsed time or 0.7 hrs. If the delivery position of the arriving vehicle is directly above the capture position, the $\overline{V}$ velocity could be negated by torquing the mechanism and allowing the Orbiter to coast using the r residual velocity. As shown on the accompanying figure for r approaches, lapsed times are characteristically shorter for the assumptions made than $\overline{V}$ approaches once the vehicle is on the mechanism. An advantage of the $\overline{V}$ approach is the ability to target the arriving vehicle on a non-collision course with the Space Station.

CAPTURE-TO-DOCK LAPSED TIME vs IMPULSE AND $\bar{V}$ VELOCITY FOR FOUR BAR LINKAGE SYSTEM

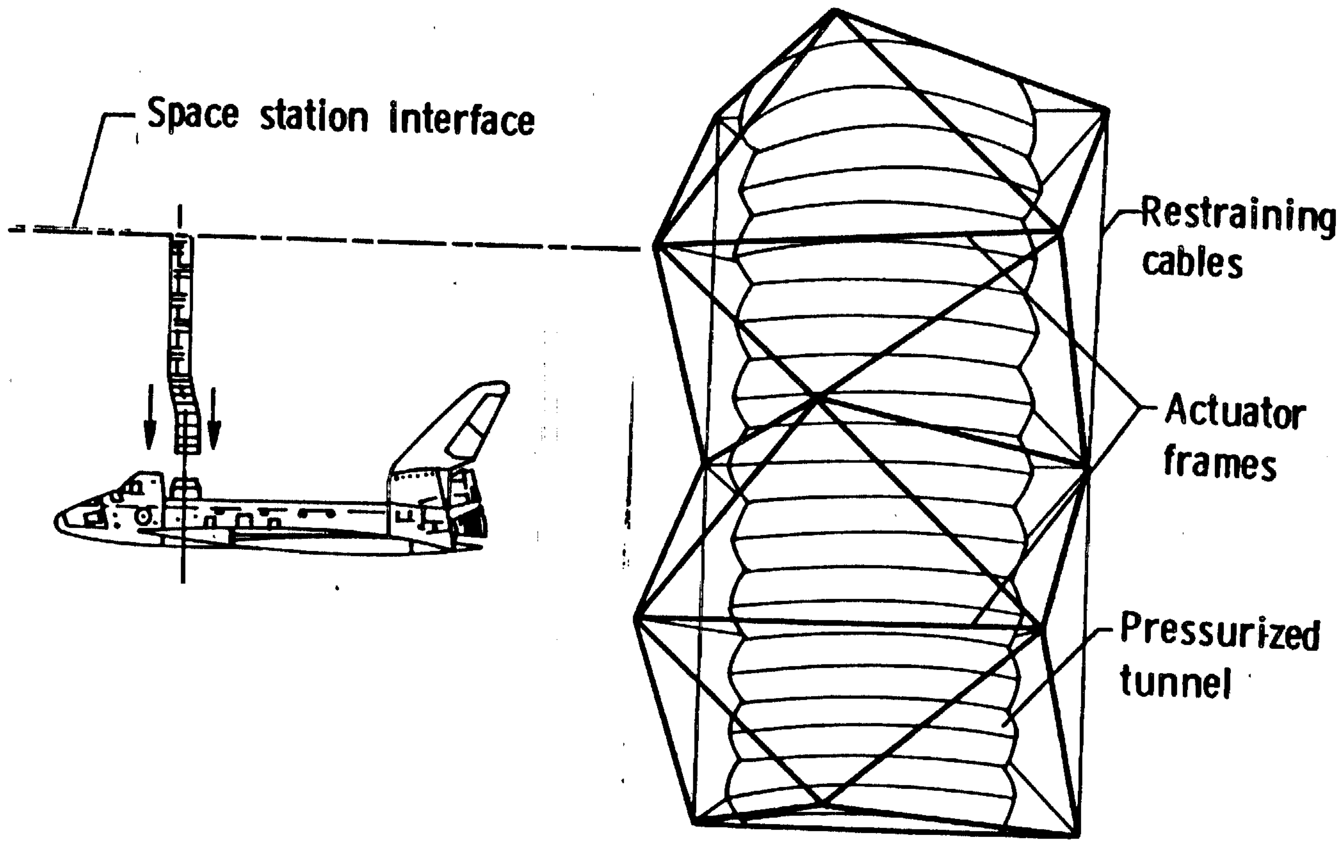


GEODESIC BEAM TUNNEL

Another option for the docking of the Shuttle or other vehicles at some distance from the Space Station may be the geodesic beam tunnel. Personnel would be transferred through the tunnel. The tunnel is deployed by pressure with cables attached to corners of the fixed frames to control the deployment rate. Telescoping members in the actuator frames allow the beam to extend and contract. Solenoid clamps on the cable at fixed frames control the axial and radial displacements of the beam.

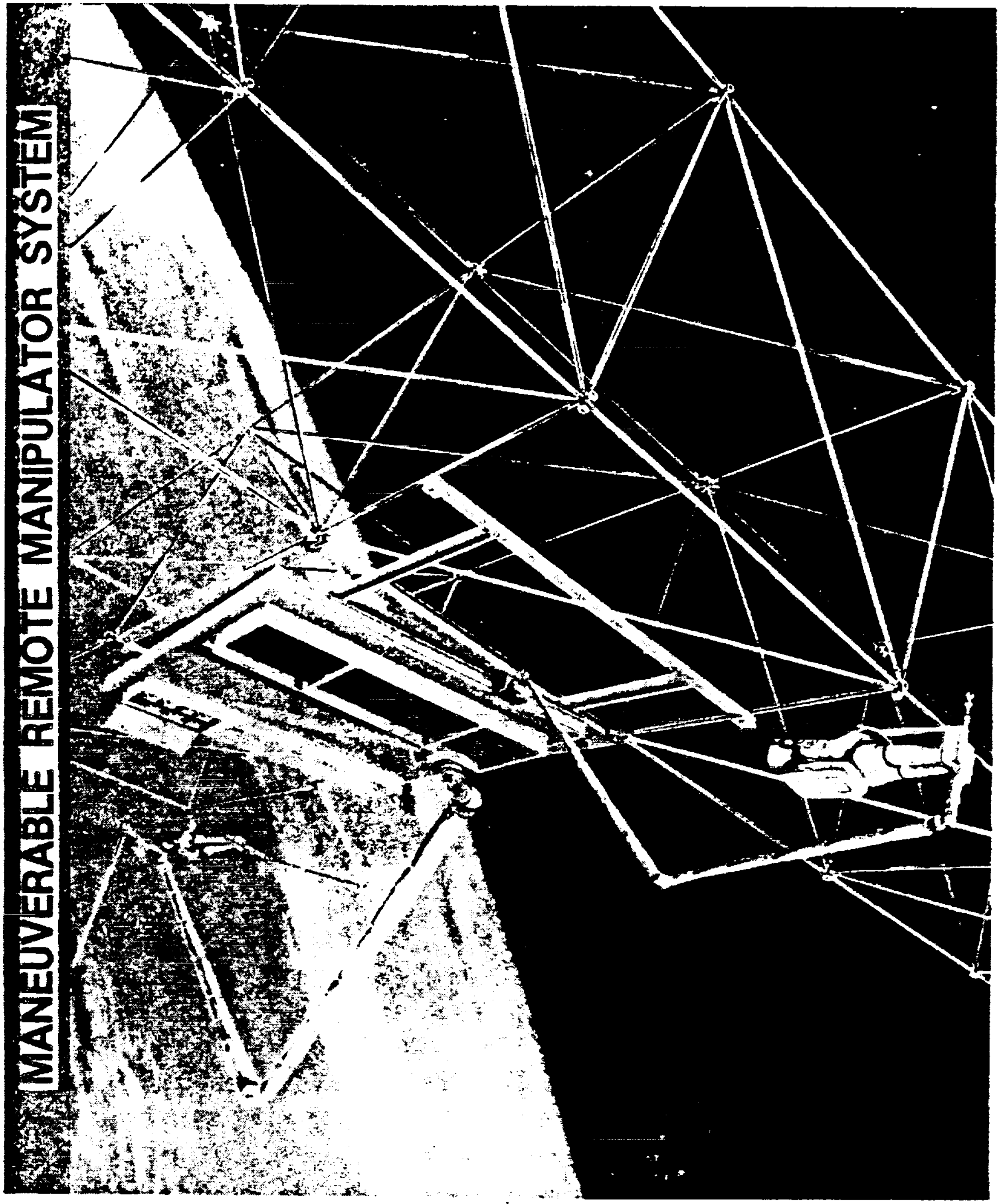
A two-bay geodesic beam development model, which is controllable both in axial and radial movement, has been constructed and demonstrated in the laboratory at the Langley Research Center. This two-bay model will accommodate a 28" diameter tunnel, packaged in a length of approximately 5 inches, and deploys to a length of approximately 96". There are no known design or technological barriers for making much longer and larger diameter deployable structures for docking incoming vehicles. End effectors on the geodesic tunnel would be provided for actively capturing the docking ring of an incoming vehicle. Tunnel mechanism could be rendered pliant during actual docking to prevent overload.

GEODESIC BEAM TUNNEL



NON-ROUTINE OPERATIONS ON THE SPACE STATION USING A MANEUVERABLE REMOTE MANIPULATOR SYSTEM

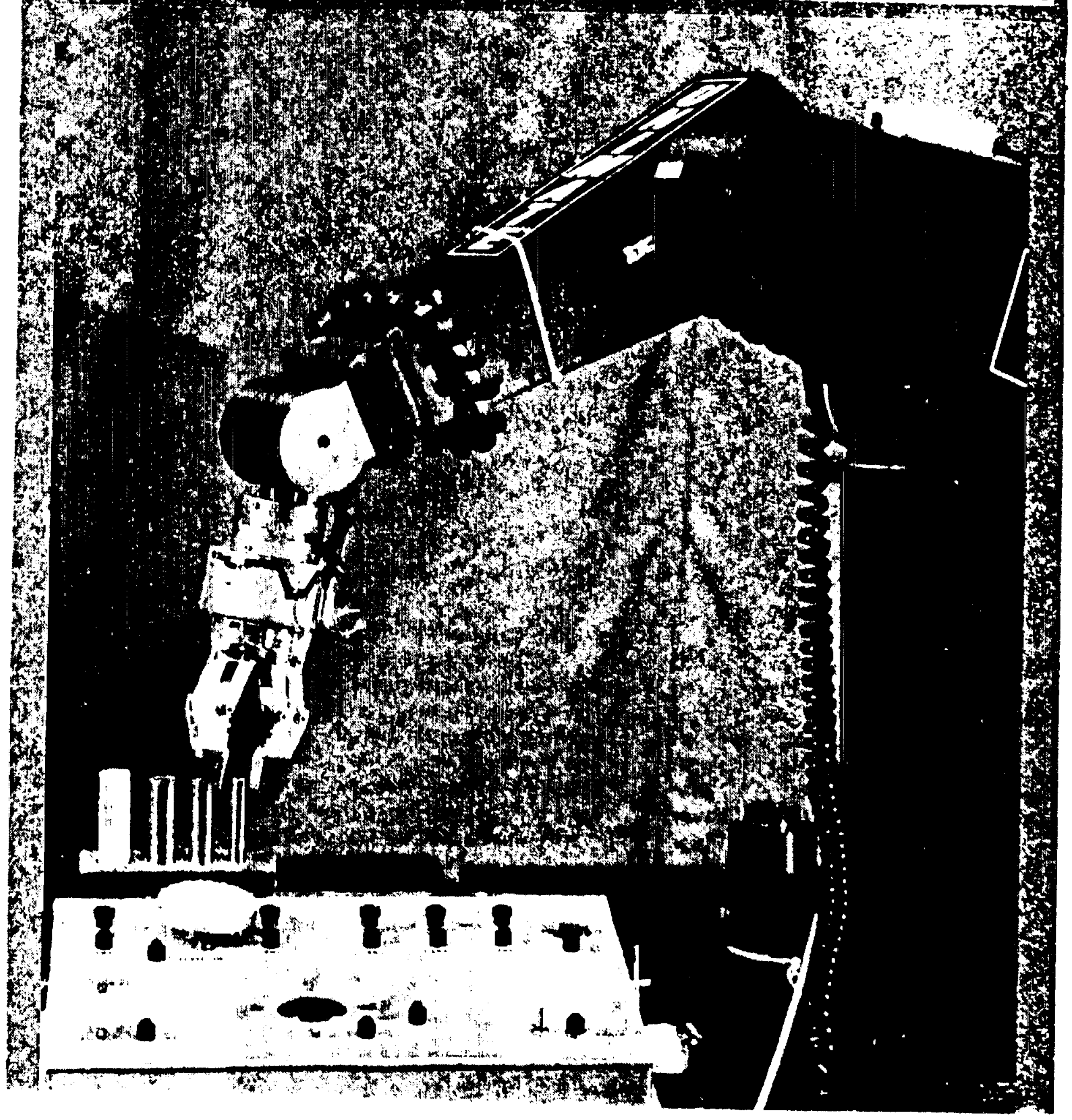
For non-routine operations on the station a mobile remote manipulator system (MRMS) has been proposed. Such a system is shown with astronauts on two of the manipulator arm work platforms. A system of this type could be used for the assembly of large space structures and for other non-routine tasks. The base of the manipulator steps along from node-to-node of the structure; no guide rails are required (REF. TM 86262). Because the system could be driven by a rack and pinion or some type of leadscrew, very accurate positioning of the system is possible.


MANEUVERABLE REMOTE MANIPULATOR SYSTEM

MANIPULATOR SUPPORTIVE RESEARCH
APPLICABLE TO SPACE STATION PROXIMITY OPERATIONS MECHANISM DEVELOPMENT

A remotely controlled manipulator is currently being used in research in the LaRC Flight Dynamics and Control Division. The six-degree-of-freedom manipulator has force and torque sensors in the wrist and fingers, and proximity sensors in the fingers. The unit is controlled from a manned control station having a TV and computer graphics. Much of the technology is applicable to the development of capture and manipulator systems needed in the total Space Station transportation proximity operations system. The research would be directly applicable to the development of the manipulator systems on the MRMS just described.

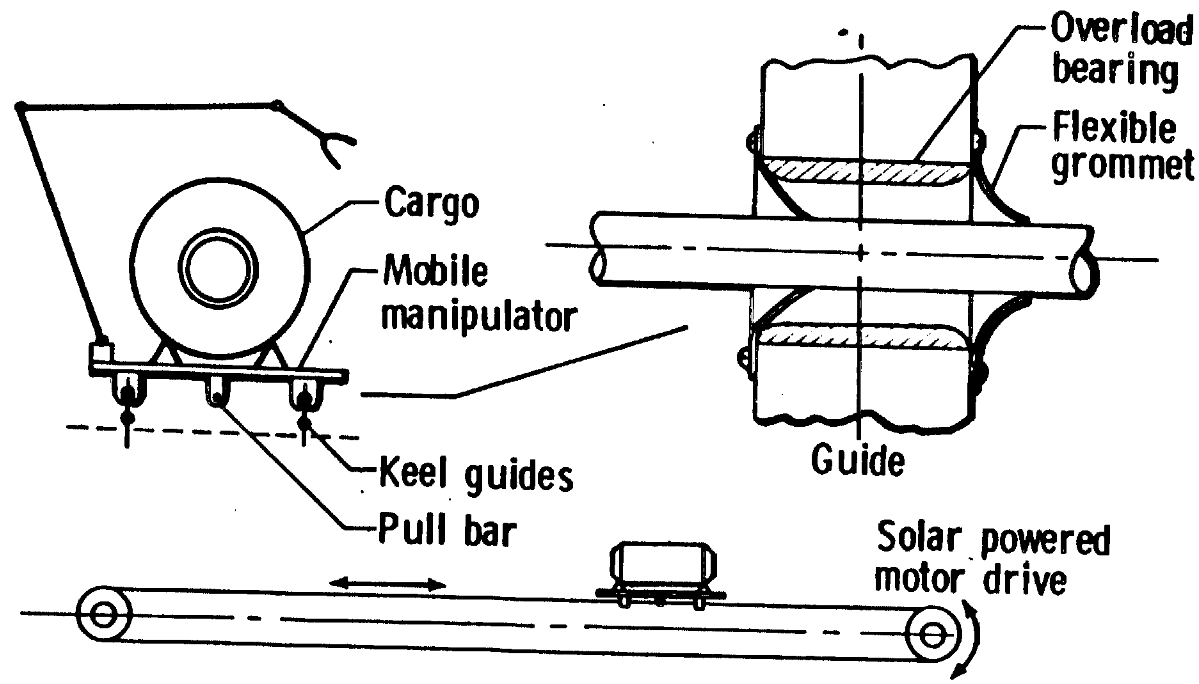
MANIPULATOR SUPPORTIVE RESEARCH



ROUTINE CARGO TRANSFER SYSTEM

For routine cargo transfer up and down the Space Station keel, some type of mobile manipulator (already shown by others) would be useful. In the proposed design, a solar powered motor drives a cable around two pulleys at either end of the station keel. Guide rails are mounted on the keel structure. The flexible teflon grommet shown would give low frictional resistance while keeping the guide rail centralized in the carriage bearing. The large teflon bushing would serve as a restraint in the event of large dynamic loads on the manipulator unit. Solenoid actuated clamps would be used to restrain the manipulator carriage during loading and unloading or during any operations for which high rigidity is required. Some type of magnetic levitation and drive may be an alternate method for carriage suspension and drive.

ROUTINE CARGO TRANSFER SYSTEM



TRANSFER ALONG SPACE STATION KEEL
VELOCITY PROFILES

In the accompanying figure, velocity versus time profiles are whown. Profile (A) is for the MRMS which translates in a stepwise fashion between structural nodes. Profiles (B) and (C) are for routine cargo transfer systems wherein the mobile manipulator is mounted on guiderails. In all three profiles, a 20,000 lb cargo is assumed for transfer along a 390 ft keel with a maximum allowable impulse during the transfer on the Space Station structure of 500 lb-sec. Constant accelerations and decelerations are assumed for all velocity changes. For the MRMS, a 15 ft spacing between keel structure nodes is assumed.

For the MRMS stepwise drive (profile A), 26 acceleration and 26 deceleration impulses are alternately applied to the Space Station over 7.5 ft half node distances to give a total displacement of 390 ft. Each impulse consists of a 26.8-lb force acting for 18.63 seconds. (Note: For the assumptions made, only one set of values for force and lapsed time satisfies the 500 lb-sec impulse and selected nodal distance.) The lapsed time for travel along the 390 ft keel is 969.4 seconds (0.27 hrs).

For the routine cargo transfer system on guiderails, two operational transfer modes are considered in accordance with velocity profiles (B) and (C). In (B), the 20,000 lb cargo is subjected to a constant acceleration for one half of the required keel distance and decelerated for the second half. For this operational mode, the applied force is 1.03 lb acting for 484.5 seconds, or 969 seconds (0.27 hrs) for the total travel. The lapsed time is identical to that for the stepwise transfer. (It can be shown from the equations of motion and the assumption of a single value of impulse, that the lapsed times will be identical irrespective of the number of contiguous impulses of equal magnitude utilized.)

Profile (C) represents an operational mode in which an impulse of short duration is applied followed by a long coast period and finally a short braking impulse. When a 10-lb force is selected to act over a 50 second time period for both acceleration and deceleration with a long coast period, the lapsed time to travel the 390 ft is only 534.8 seconds (0.15 hrs) or is approximately half that for profiles (A) and (B).

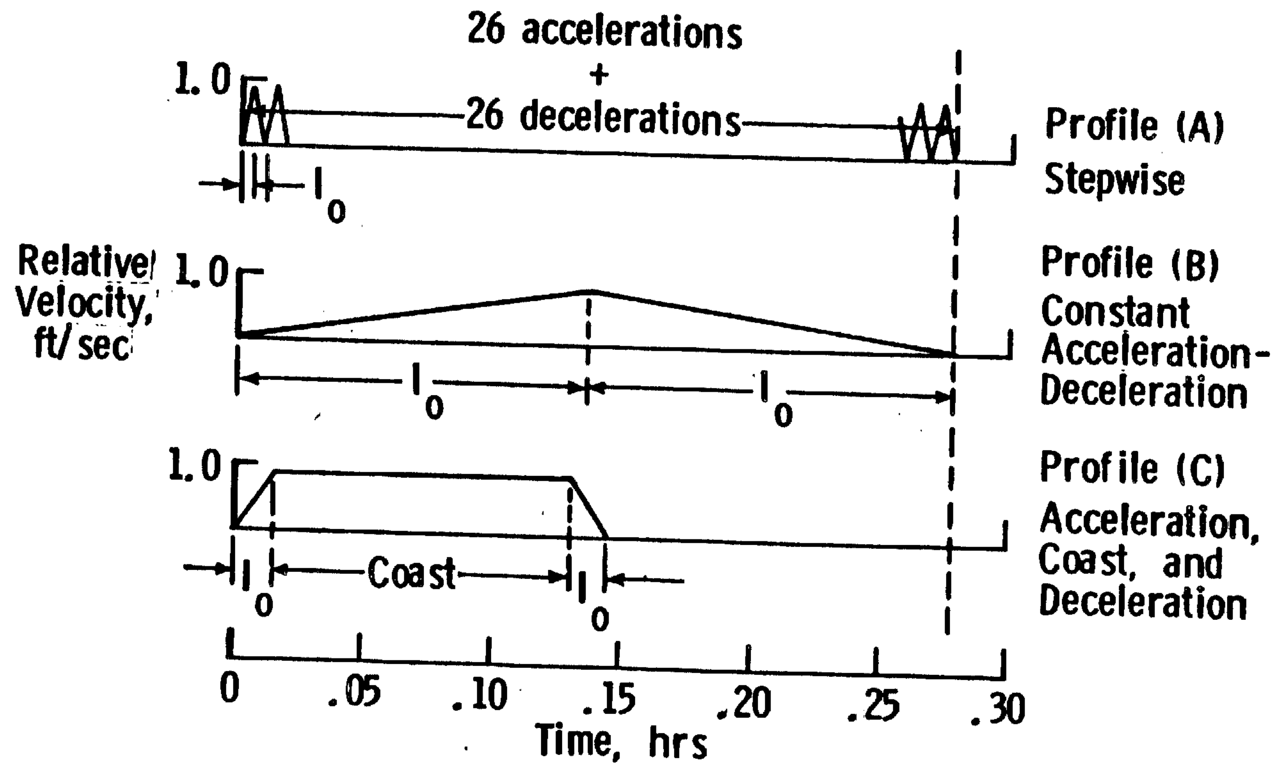
TRANSFER ALONG SPACE STATION KEEL: VELOCITY PROFILES

Assumptions:

Mass = 20,000 lbm

Distance = 390 ft

Max. impulse, I_0 = 500 lb-sec



TIME REQUIREMENTS FOR OTV PROCESSING COMPARED TO TIME FOR TRANSFER OF CARGO ALONG KEEL

An issue in berthing and docking vehicles and in moving cargo around a Space Station is: How important is a rapid point-to-point transfer when this lapsed time is compared to other routine operations? In the accompanying table, time estimates are repeated from NAS 8-3509 in which processing an Orbital Transfer Vehicle (OTV) on the Space Station is discussed. For illustration, the OTV can be regarded as cargo which must be moved along the Space Station keel as the payload is integrated, propellant is loaded, and other processing functions performed. In the previous discussion related to velocity profiles, transit times were reduced by 45% by utilizing short period impulses with an intermediate coast period. In this regard, the transit time calculated for rapid routine cargo transfer was 0.15 hrs. This lasped time can be compared to one of the longer example operations, namely 6.0 hours for propellant transfer. Analysis is needed to identify the relative importance of rapid transfer times on-station when compared to other operations, such as the example above.

A secondary issue is the rapidity with which cargo is transferred relative to the strength of the structure and, in general, safety considerations. In all the examples shown, a 20,000 lb cargo was assumed. The given impulse of 500 lb-sec establishes the peak velocity of 0.804 ft-sec along the Space Station keel for the cargo. If the cargo mass is only 2000 lb, the peak transfer velocity could be increased to 8.04 ft-sec for the 500 lb-sec impulse limit (somewhat greater than a walking pace). Moving cargo faster would necessitate quicker responses on the part of the Space Station crew and systems. Stopping a moving cargo with a momentum of 500 lb-sec (in 1 second for example) due to jamming of the mobile carriage or other equipment failure, could result in a 500 lb force being suddenly applied to the Space Station structure. A deterrent to such a system failure may involve the use of a "friction" pallet which was constrained, but slides a short (but finite distance) if the carriage jams on its guiderails.

TIME REQUIREMENTS FOR OTV PROCESSING COMPARED TO TIME FOR TRANSFER ALONG KEEL

TASKS	TIME, HOURS
O OTV*	
RESIDUAL PROPELLANT TRANSFERS	1.8
INSPECTION AND PLANNING	2.8
SYSTEM TEST	0.8
PAYLOAD INTEGRATION	5.3
PROPELLANT TRANSFER	6.0
O TRANSPORTATION PROXIMITY OPERATIONS	
TRANSFER 20 KLB CARGO 390 FT ALONG KEEL	0.15

*FROM NAS8-35039 (GDC REPORT NO. GDC-SP-83-067)

PROPELLANT TRANSFER

In the accompanying figure, one scenario for propellant transfer on orbit is shown. The basis of the system is a 50,000 lb capacity delivery module 14 ft x 37 ft carrying propellant at a mixture ratio of 6 to 1. An allowance of 15,000 lb is made for tanks, structure, insulation, support, and other subsystems.

In one mode, the module is delivered to orbit by the Shuttle Orbiter and the four-bar mechanism engages the four capture bars which are deployed from the sides of the module . The mechanism then transfers the tank module (C) full of propellant to the propulsion module (D). No on-orbit propellant transfer is required.

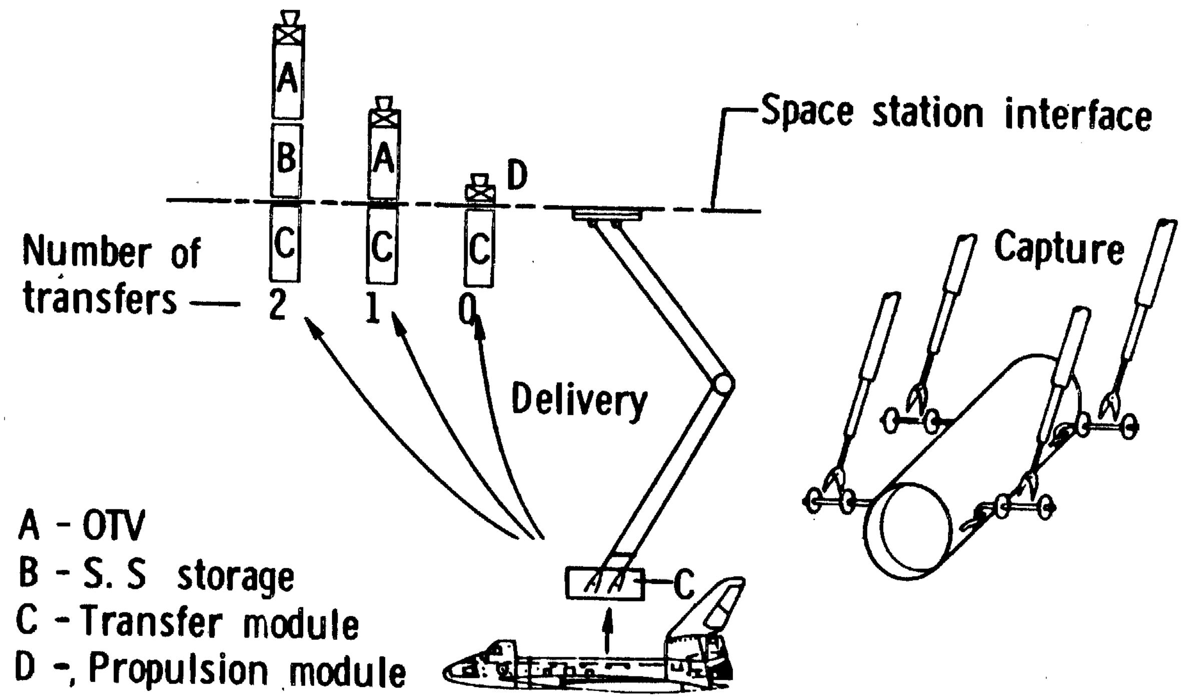
In a second mode, module (C) is delivered by the Orbiter, and the module is positioned for transfer of the propellant to the tanks of a space-based OTV (A). Because the OTV is space based, much lighter insulation systems can be used, in particular, because the ambient condition is a vacuum. Also, structurally, the tanks will be lighter because the design thrust-to-weight of an OTV engine at ignition is characteristically about one tenth that of an Earth-to-orbit rocket propulsion system.

In a third mode, module (C) is delivered to the Space Station, and the propellant is transferred to space based storage tanks (B). The tanks and insulation are similar in material usage and construction to the OTV tankage (A). The propellant is kept in storage until required by the OTV or other space based vehicle.

When comparing the three modes, mode one requires no transfer of propellant on-orbit, mode two requires one transfer, and mode three requires three. The initial loading on the launch pad with module (C) in the Shuttle is not counted in the above transfers.

Efforts are being made to develop a program which will calculate losses for transfer and storage for various propellant handling systems configurations. Published data and various experts in the field are being consulted. More actual space experience is needed to establish better parameters for long term storage boil-off and chilldown losses during transfer.

PROPELLANT TRANSFER



A - OTV
B - S. S storage
C - Transfer module
D -, Propulsion module

SUMMARY REMARKS

Disturbances to the Space Station will be directly related to the momentum of the incoming vehicles. Techniques need to be developed to minimize these momentum magnitudes. The Shuttle Orbiter, because of its heavy mass, will have an arrival momentum that will be difficult to minimize. Attaching vehicles to the station on a long mechanism minimizes potential contamination to the station but makes docking vehicles with $\overline{V}$ residuals more difficult because of the larger torquing arm from station c.g. to vehicle attachment point.

Some type of rapid transfer system is needed for moving cargo, vehicles, and payloads around the Space Station during routine processing. Also, a device for non-routine movement of cargo around the Space Station should be studied. This device should be capable of operating on curved surfaces such as antennas, on solar panels, or other (irregular) structures.

Values for allowable docking impulses (ref: JSC-19989) were used as benchmarks in identifying allowable values of impulses for the transportation system functions. However, the transportation system operations need to be modeled, particularly the effects of cargo on the Space Station and impulse limits need to be reviewed for these functions.

As a general observation, the Shuttle Orbiter will probably design the berthing-docking systems for the forseeable future, this vehicle having the largest mass (and, therefore, momentum) for a given arrival velocity. An additional technical area will be that of transporting and transferring propellants. The subject is only superficially dealt with here but is projected to constitute 70% of the mass handled on orbit in the future. Additional experiments in space are needed to determine boil-off rates for cryogenic propellants stored on orbit and transfer phenomena under zero g conditions.

SUMMARY REMARKS

- O A MECHANISM HAS BEEN IDENTIFIED FOR ARRIVALS AND DEPARTURES OF VEHICLES AT A SPACE STATION
- O A MECHANISM FOR ROUTINE TRANSPORT OF CARGO UP AND DOWN THE SPACE STATION KEEL HAS BEEN PROPOSED
- O A DEVICE (PROPOSED BY OTHERS) WHICH TRANSLATES IN A STEPWISE FASHION HAS BEEN SHOWN WHICH COULD BE USED BOTH FOR ROUTINE AND NON-ROUTINE CARGO HANDLING
- O THREE OPTIONS FOR HANDLING PROPELLANTS AT A SPACE STATION HAVE BEEN IDENTIFIED

MDC H1464
20 FEBRUARY 1985

BERTHING MECHANISMS

GENE C. BURNS

Rendezvous and Proximity Operations
Workshop – Mechanisms Subsession
NASA, Johnson Space Center
Houston, Texas

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-HUNTINGTON BEACH

MCDONNELL DOUGLAS
CORPORATION

5A-85

Presentation No. 4, Berthing Mechanisms
Gene Burns, McDonnell Douglas Astronautics Company

With the Space Station program underway, the requirements for mechanisms to berth and structurally attach, on-orbit, large elements of the Space Station become real hardware specifications leading to the development and qualification of these mechanisms over the next few years.

PROLOGUE

We have done it before. The first pressurized interface on-orbit was accomplished by the USA for the Apollo program to dock the command module to the LEM. Later, the same system was used on the Skylab program to dock the command module to the Skylab airlock. This mechanism was called a docking system as opposed to a berthing system. These terms are defined as follows:

- Docking – The engagement capture and structural attachment in space of two free bodies initially having significant relative velocity and misalignment of mating interfaces.
- Berthing – The engagement and structural attachment of two bodies in space using a manipulator link between the two bodies to control and mate the interfaces.

Figure 1 illustrates the Apollo docking system. A drogue assembly was preassembled into the passage on one side of the interface, and a probe and capture latch assembly was preassembled into the other side. After capture, the probe retracted to bring the pressure seal and structural latches into contact. The 12 latches were then operated to secure the interface. To provide the crew with pressurized access through the interface, the probe and drogue were manually removed and stowed.

Figure 2 illustrates the Apollo Soyez Test Program docking system. This system utilized a three-

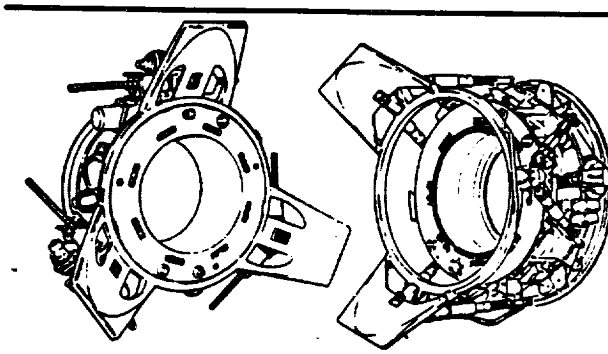


Figure 2. Apollo/Soyuz Test Project Docking Systems

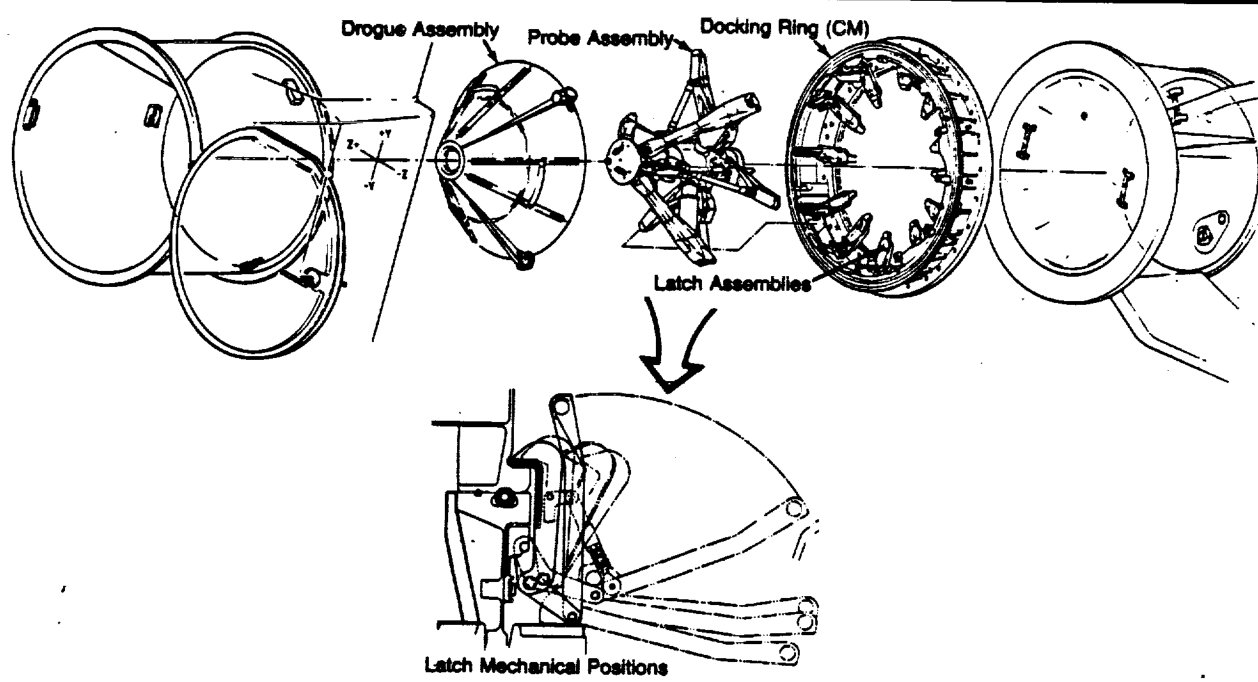


Figure 1. Apollo/Skylab Docking System

guide capture latch mechanism supported on six hydraulic attenuators. This truly androgynous system provided the crew with a clear-passage diameter, after docking, of 0.8 m, without the removal of the capture mechanism.

Figure 3 illustrates a docking concept that was considered for use during the Space Station Phase B study during the early 1970s. This concept used a square capture frame with guides/latches installed at two of the four corners. The frame, mounted on eight attentuators/actuators, retracted to mate the structral interface and pressure seal. This concept, used in conjunction with a large (60-in. diameter) passageway, provided shirt-sleeve access to the berthing mechanism.

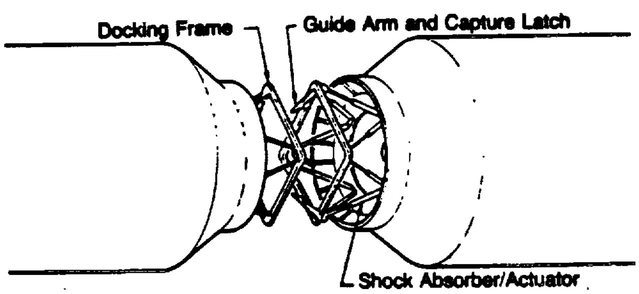


Figure 3. Square-Frame Docking System

During the late 1970s and early 1980s, shuttle-tended unmanned space platforms were being studied. These platforms required that structrual elements of the platform assembly and payloads be attached in orbit and that the shuttle be berthed during resupply visits. A study of berthing mechanisms was conducted, resulting in the design and fabrication of a working model of a berthing latch interface mechanism (BLIM) (Figures 4 and 5). This mechanism utilized an active and a passive half and combined the capture latch and structural latch into a single mechanism. The BLIM frames were supported on six struts, which were rigid on the model but could be designed to be active for alignment and energy attenuation during the berthing sequence. The mechanism was designed for unpressurized application; however, a 1-m clear center opening was maintained for possible pressurized module applications. Figure 6 illustrates the design of retractable umbilical carriers to be used in conjunction with the BLIM. These umbilical carriers are extended after the two halves are mated to provide the electrical and fluid connections across the interface. This mechanism was designed to accommodate a berthing operation similar to that anticipated for the Space Station. Following are the key requirements that were derived at that time:

- Closing rate – 0.1 ft/sec.
- Angular rate – 1.0-deg/sec pitch, roll, and yaw.
- Lateral mismatch – 4 in.
- Angular mismatch – 10-deg pitch, roll, and yaw.

SPACE STATION BERTHING

Figure 7 represents the current reference configuration Space Station as defined by NASA. The configuration contains unpressurized payload interfaces, semipermanent pressurized module-to-module interfaces, transient pressurized module interfaces, and shuttle-to-Space Station pressurized interfaces.

The current philosophy for mating all interfaces on the Space Station is that mating will be an operation using either the orbiter remote manipulator system (RMS) or the station manipulator in a highly controlled, low-velocity berthing process. This leads to the conclusion that there will be no need for active shock attenuation as part of the interface mechanisms. Mating the interfaces of the Space Station elements will be a process similar to berthing a payload in the orbiter payload bay and engaging the payload trunnions with the active orbiter longeron and keel journals. Other requirements for the module-to-module interface are:

- Androgyny – A physical interface capable of mating with any other identical interface.
- Passage size – The clear passageway shall be consistent with a 50-in.-diameter, D-shaped hatch, as a minimum.
- Umbilicals – Provisions for both remotely and manual hookup of umbilicals will be provided.
- Structural latches and seals – To accommodate pressure loads and dynamic loads of the mated elements.

The semipermanent module-to-module interface of the reference configuration represents a unique requirement because of the closed-loop or race-track module arrangement. Figure 8 represents the reference configuration module arrangement and the potential angular misalignment of the interface resulting from manufacturing tolerances and temperature differentials. Assembling this module pattern requires that the interfaces have flexibility built in to compensate for the tolerances. We found that 2 degrees of freedom at the interface will satisfy the alignment and assembly of this module pattern. The challenge is to design a flexible interface that will withstand the

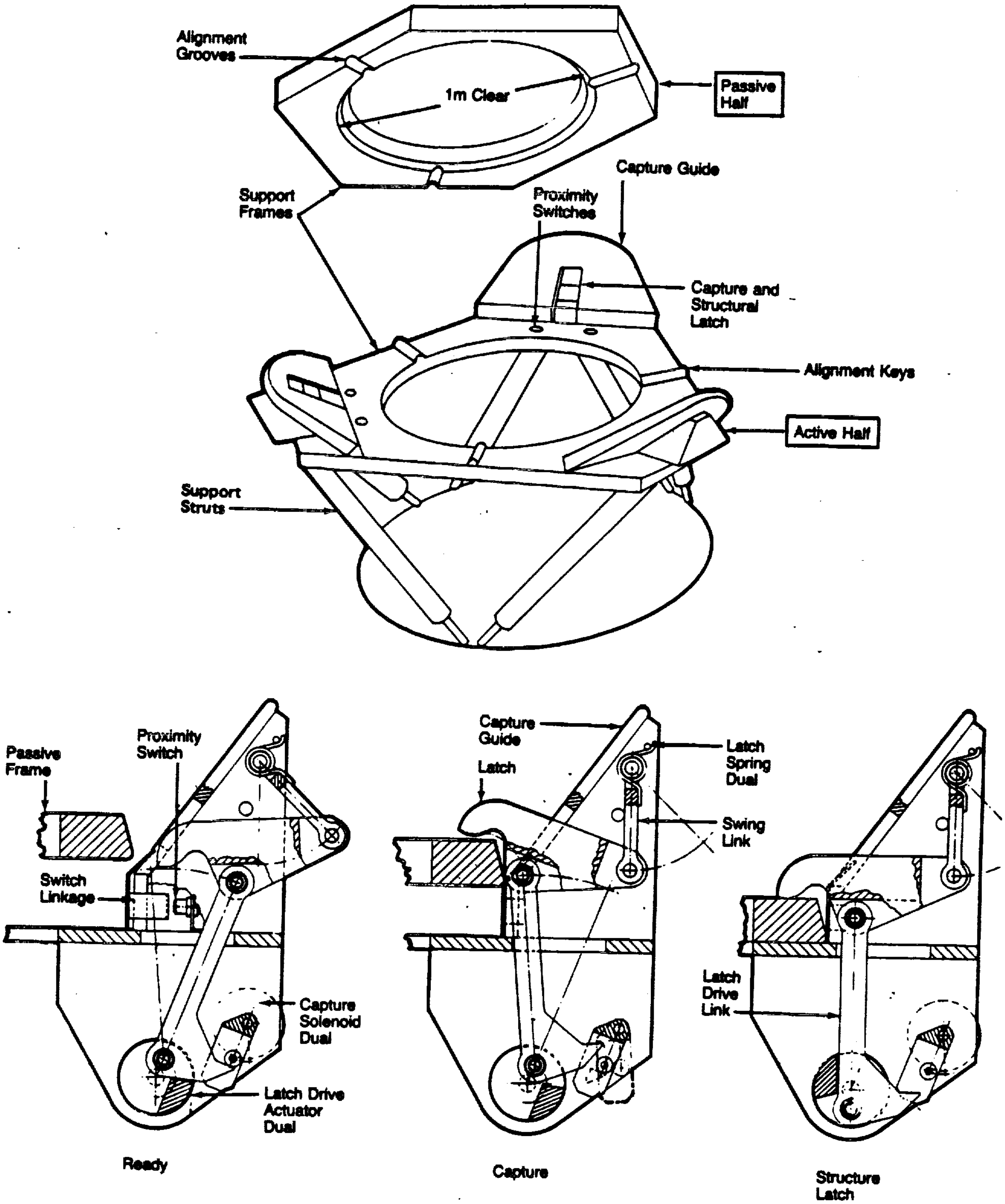


Figure 4. Hexagonal Frame — Berthing Latch Interface Mechanism (BLIM)

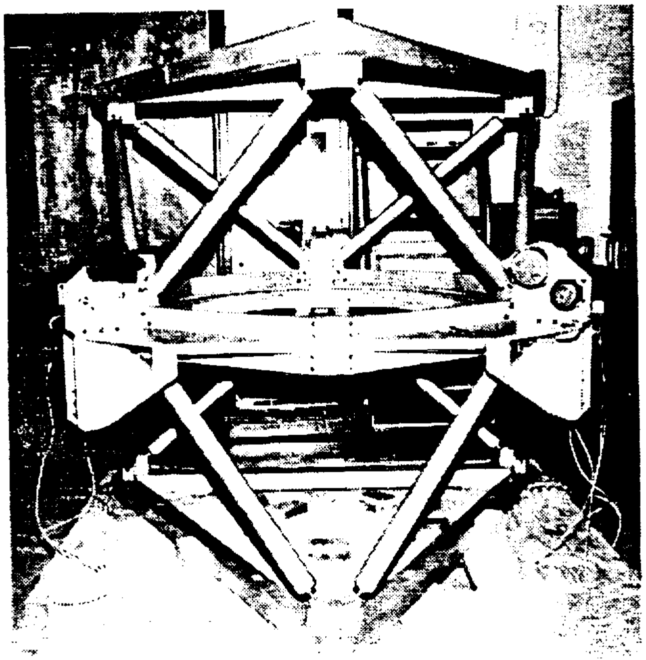


Figure 5. Full-Scale Working Model of BLIM

tension load imposed by the internal pressure in the modules.

Figure 9 illustrates one potential design solution for the berthing interface for this specialized application. This concept uses a metal bellows for flexibility and a double gimbal to carry the tension load created by the internal pressure. This flexible coupling will be necessary only on one side of the four module interfaces. It can therefore be added to one end port of each of the modules in the pattern. All other berthing ports on the modules will have a rigid interface.

ORBITER BERTHING

The berthing of the orbiter to the Space Station will utilize the same operational procedure as module-to-module berthing. The orbiter and the Space Station will be mated using the orbiter or the Space Station RMS. However, because of the large mass of the two elements being mated, it may be desirable to provide an active energy attenuation and alignment compensation system on one side of the interface. This system, as shown in Figure 10, would utilize an extendable frame with the capture guides identical to the passive interface configuration.

The ring is supported on eight shock-absorbing damper springs that provide energy attenuation and alignment compensation during initial engagement and stabilization. After stabilization, the electromechanical shock absorber/springs serve as actuators that retract the frame and mate the structural interface. Figure 11 illustrates an example of our electromechanical spring/damper/actuator currently under investigation for use in Space Station berthing mechanisms.

CONCLUSIONS

The Space Station presents these four unique berthing interface conditions that must be accommodated:

- Module-to-module pressurized rigid.
- Module-to-module pressurized flexible.
- Orbiter-to-Space Station with energy attenuation.
- Payloads/orbiter-to-Space Station unpressurized.

For the sake of commonality and operational flexibility, these interfaces should all be designed to mate with each other mechanically. Our history shows that we have designed mechanisms for docking in space using two basically different approaches, both of which worked. Although there are probably more variables in the berthing mechanism design for Space Station than there were for Apollo or Apollo/Soyuz Test Program, we feel that the design challenge is to make these mechanisms simpler, lighter, maintainable, and with a high degree of commonality. The work of formulating concepts for berthing mechanisms is progressing. Over the next 18 months, the Space Station Phase B study will establish firm requirements for these mechanisms. Within the next 2 to 3 years, we will have hardware being tested.

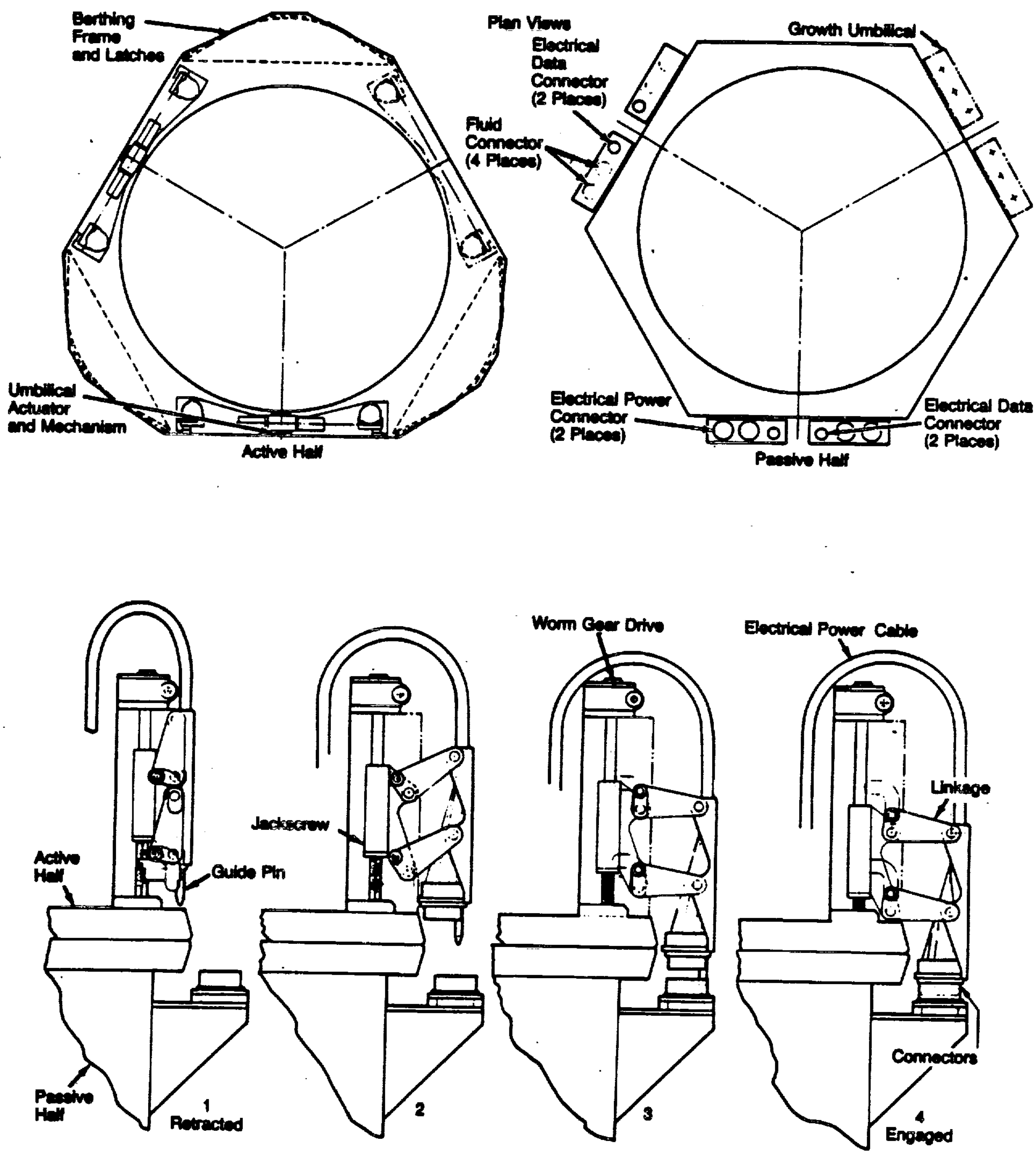


Figure 6. BLIM Umbilical Mechanism

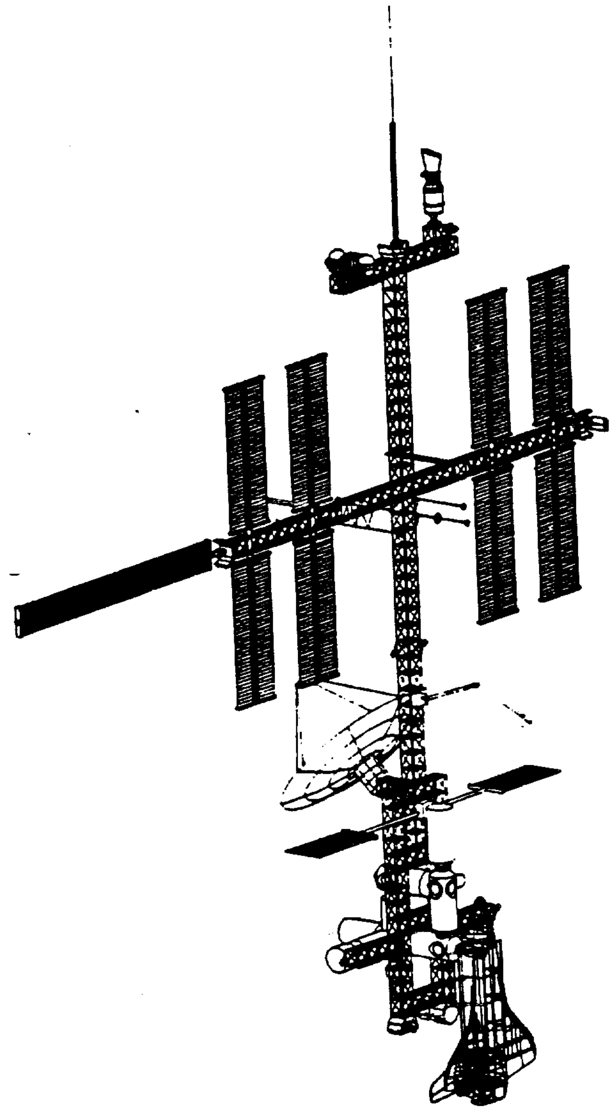


Figure 7. Space Station Reference Configuration

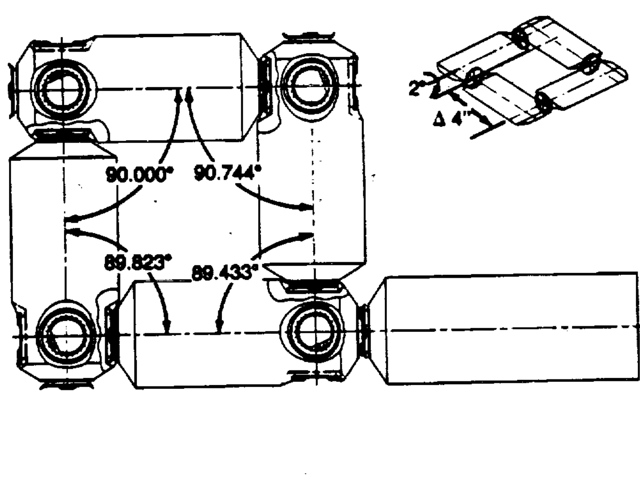


Figure 8. Reference Configuration Module Arrangement

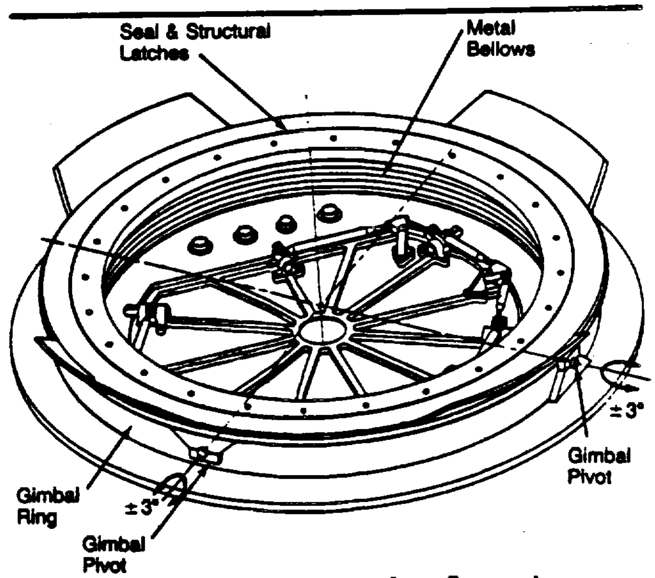


Figure 9. Flexible Module Interface Concept

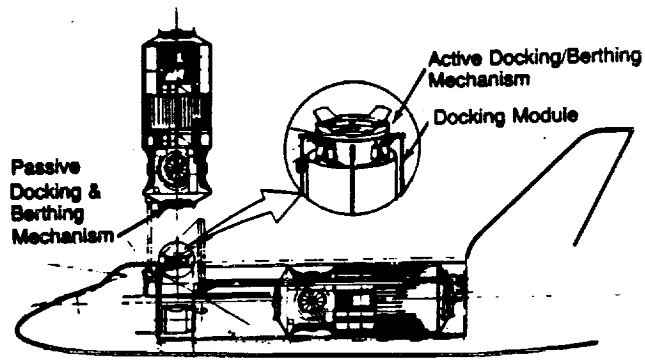


Figure 10. Orbiter-to-Space Station Berthing

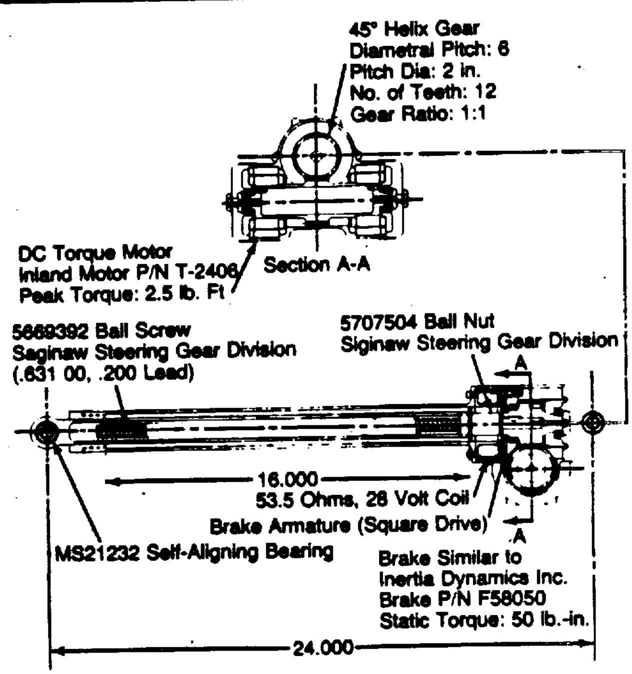


Figure 11. Electromechanical Spring/Damper/Actuator (Shock Strut) Assembly With Redundant Motors

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REMOTE SATELLITE SERVICING

Abstract

The MSFC has been performing work in the teleoperator and robotics area for a number of years in anticipation of future needs. This has resulted in unique simulation capabilities, payload servicing concepts including breadboard hardware, robotic arms, end effectors, and rendezvous and docking test bed. The purpose of this effort is to investigate and determine through simulation testing and analysis the performance, constraints, and limitations of the servicing system. Pertinent to this is the evaluation of mechanisms, remote control stations, visual systems, control modes, and other aspects that comprise the total servicing system.

REMOTE SATELLITE SERVICING

Studies by TRW and Martin-Marietta have shown, and previous flight experience has indicated, that satellite servicing in orbit is not only feasible but economical.. With the advent of the orbital maneuvering vehicle, a permanent space station and other vehicles that remain in orbit for many years, on orbit servicing will be a necessity. The viability of local EVA modular maintenance has been clearly demonstrated by the successful Solar Maximum Repair Mission. The concept envisioned here is to extend man's capability through remote servicing where it is impractical or unsafe for EVA. One concept to achieve remote servicing would be to fly a robotic servicer system on a free flyer such as the OMV in which the OMV would dock with a spacecraft requiring maintenance and perform servicing by remote operation.

The general items listed on the opposing page are believed to be some of the more important tasks that will be required. For a detailed listing of manipulator movements and tasks, the reader is referred to the MIT document "Space Applications of Automated, Robotics and Machine Intelligence Systems (ARAMIS) - Phase II", contract NAS8-34381, dated October 1983.

REMOTE SATELLITE SERVICING

REQUIRED CAPABILITIES FOR REMOTE SATELLITE SERVICING

- FLUID TRANSFER
- MODULAR EXCHANGES
- INSPECTION
- DEPLOY/RETRACT APPENDAGES
- MAINTAIN/REPAIR
- CONSTRUCTION/ASSEMBLY
- STABILIZE ATTITUDE
- CONTINGENCY CASES

REMOTE SATELLITE SERVICING

Realistic simulations are paramount to the successful design and development of remote servicing capability. MSFC has been involved for the past 12 years in a research and technology effort that has evolved into the unique simulation capability existing today. Two independent manipulator simulations basically provide automated and man-in-the-loop operation. An air-bearing mobility unit floating on a flat floor and simulating a free-flying vehicle can be associated with and support the manipulator simulations. Technology investigations follow a progression from subsystem level to system level investigations to technology readiness demonstrations that include human factors.

REMOTE SATELLITE SERVICING

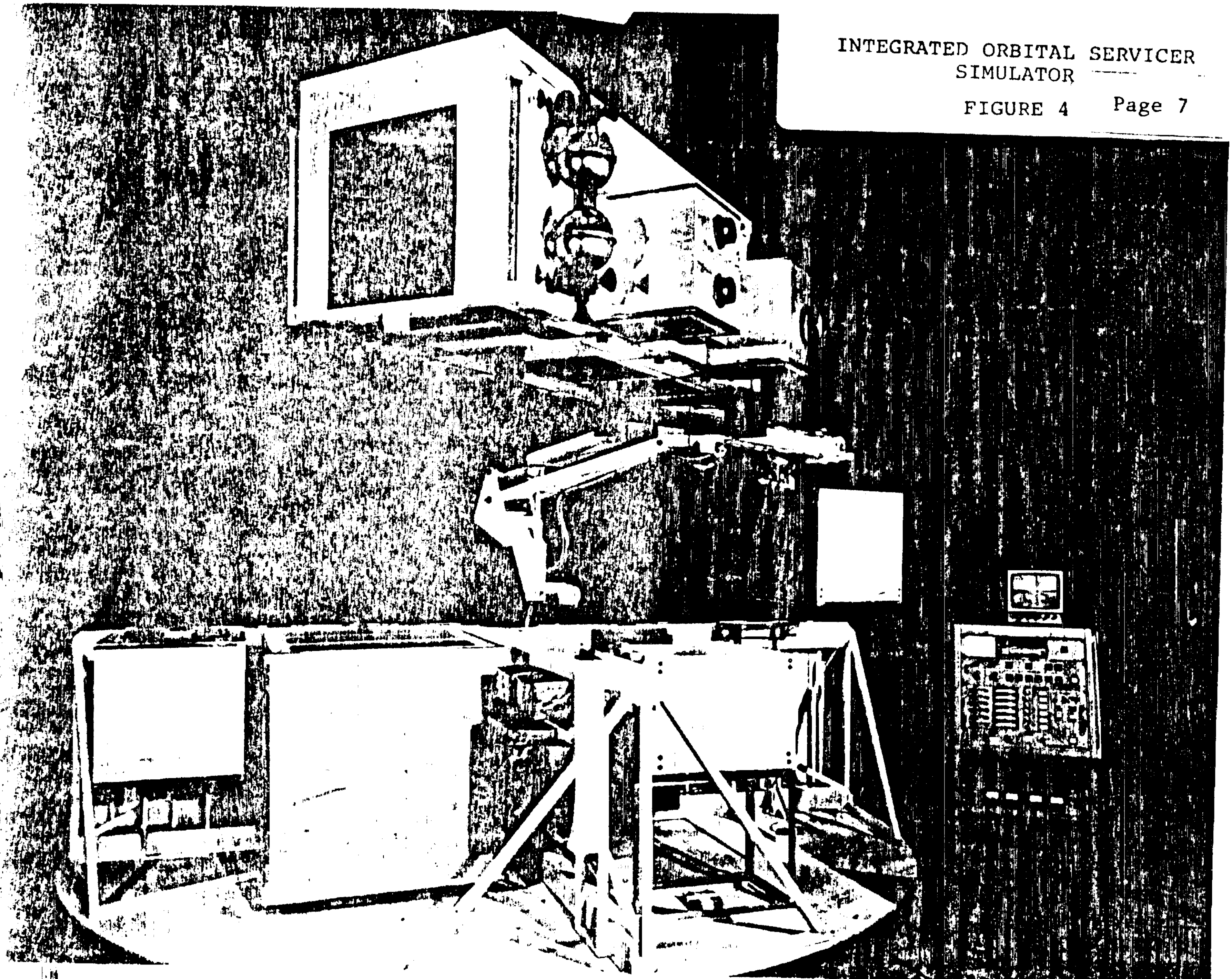
MSFC SIMULATIONS ARE SYSTEMS ORIENTED AND INCLUDE ALL SUBSYSTEMS THAT MAKE UP THE ENTIRE SERVICING SYSTEM

- MANIPULATOR ARMS
- CONTROL STATION
- INTERFACE MECHANISMS
- SENSORS
- END EFFECTORS
- SOFTWARE
- VISION SYSTEMS
- TASK BOARDS

REMOTE SATELLITE SERVICING

INTEGRATED ORBITAL SERVICER SYSTEM (IOSS)

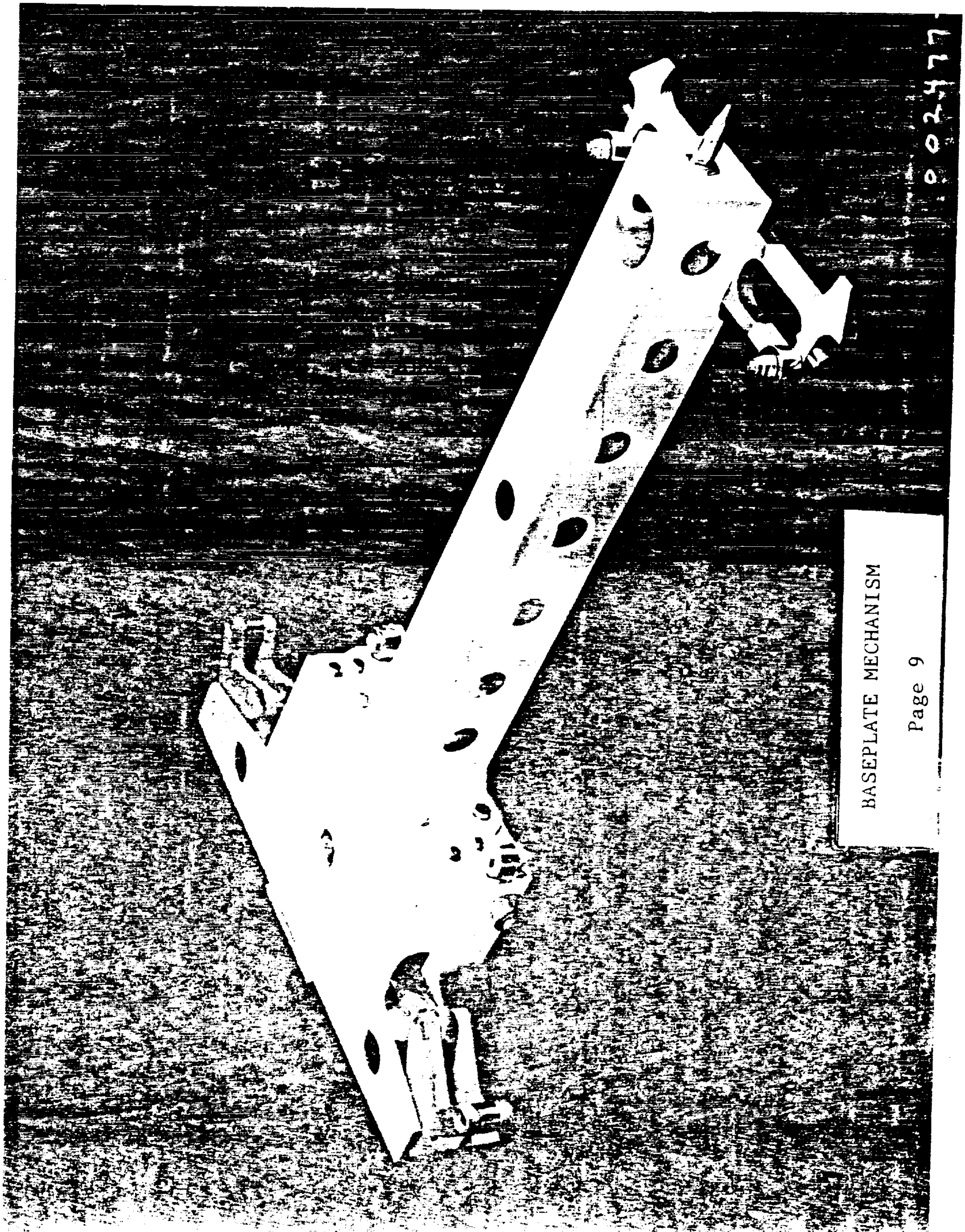
The orbital servicer system was designed specifically for satellite servicing. It is composed of a full scale orbital servicer space vehicle mockup or storage rack, a satellite spacecraft mockup, a control panel, an interface mechanism and a six-degree-of-freedom (DOF) mechanical manipulator arm. The six DOF manipulator arm and interface mechanism constitute the basis of the system. The storage rack and spacecraft are fixed relative to each other by a docking probe which simulates a hard dock of two vehicles (see Figure 4). A six DOF manipulator arm is mounted on the center shaft (docking probe) that docks the two vehicles together. A remote control panel with potentiometers, meters, indicator lights, video monitor and manual drive switches is utilized to control the arm in the manual mode which is considered the backup mode of operation. A digital computer is used for automatic control and is the primary mode of operation. The function of the six DOF arm is to remove faulty or spent modules from the spacecraft and replace them with good modules from the storage rack on the orbital servicer by either manual or automatic control. Modules are attached to the interface mechanism.



IOSS SIDE-MOUNTED INTERFACE MECHANISM

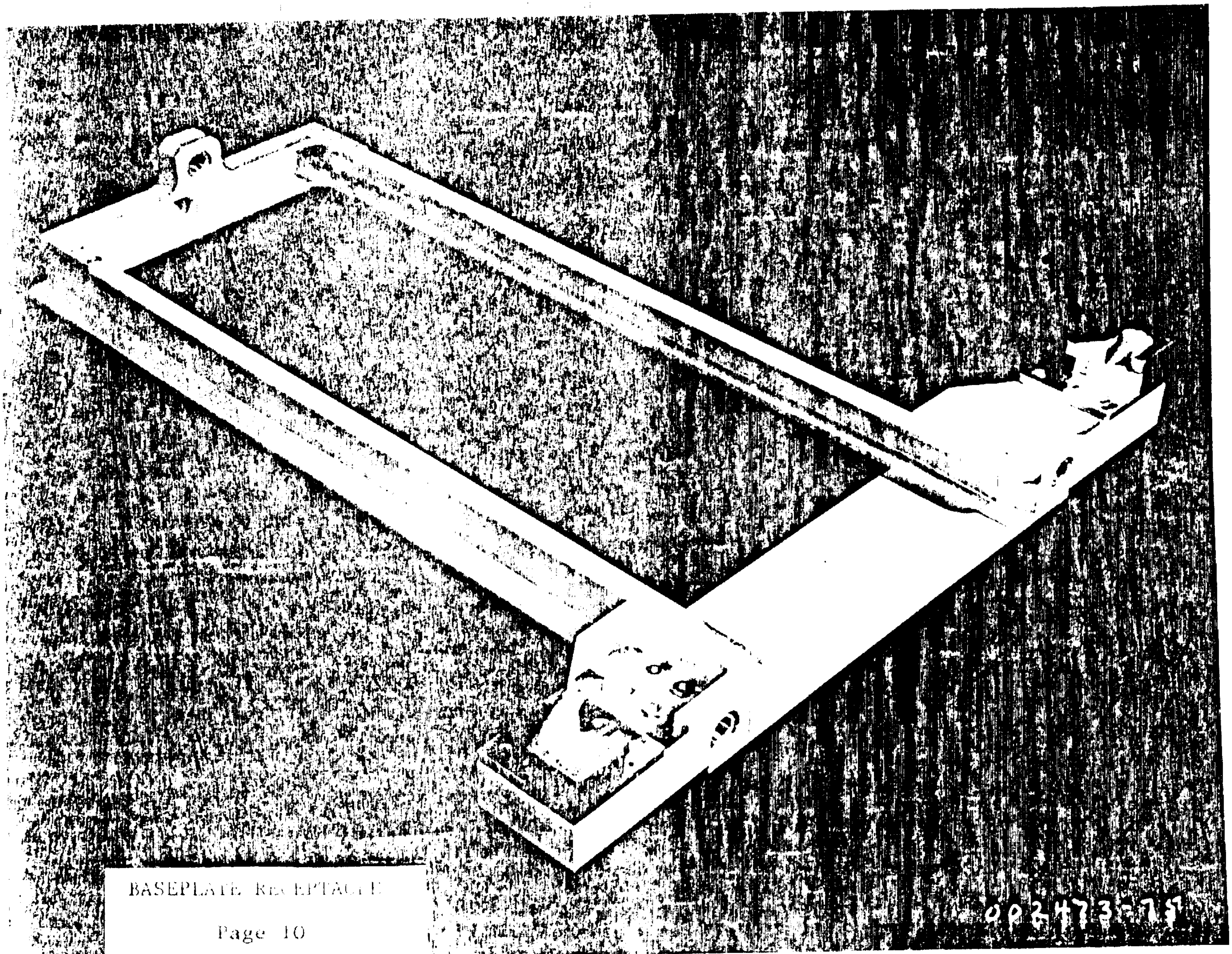
The module interface mechanisms provide the structural attachment between the module and the spacecraft or the storage rack. It also provides the alignment and mating/demating forces for the connectors. The interface mechanism has two parts; a baseplate that is fastened to the module and a baseplate receptacle that is fastened to the spacecraft. The baseplate receptacle is passive. The baseplate has the linkages, cams, and rollers that latch the baseplate into the receptable. The baseplate mechanism is mechanically driven from the servicer end effector. The interface mechanism is critical to automated modular servicing.

The IOSS will be modified to demonstrate remotely exchanging MMS modules utilizing the EVA adaptor tool mounted on the end of the manipulator arm.



BASEPLATE MECHANISM

Page 9



BASEPLATE RECEPTACLE

Page 10

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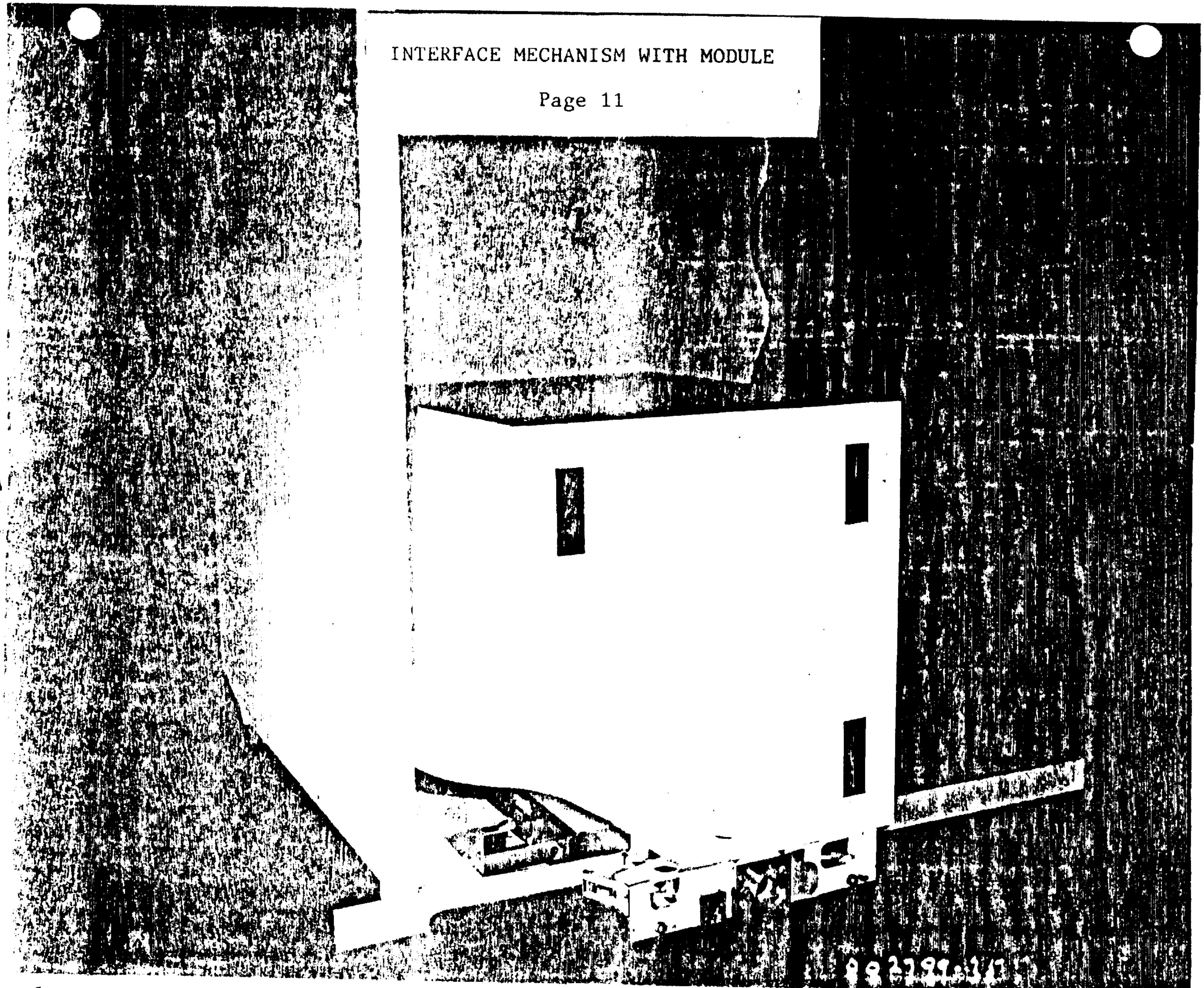
INTERFACE MECHANISM WITH MODULE

Page 11

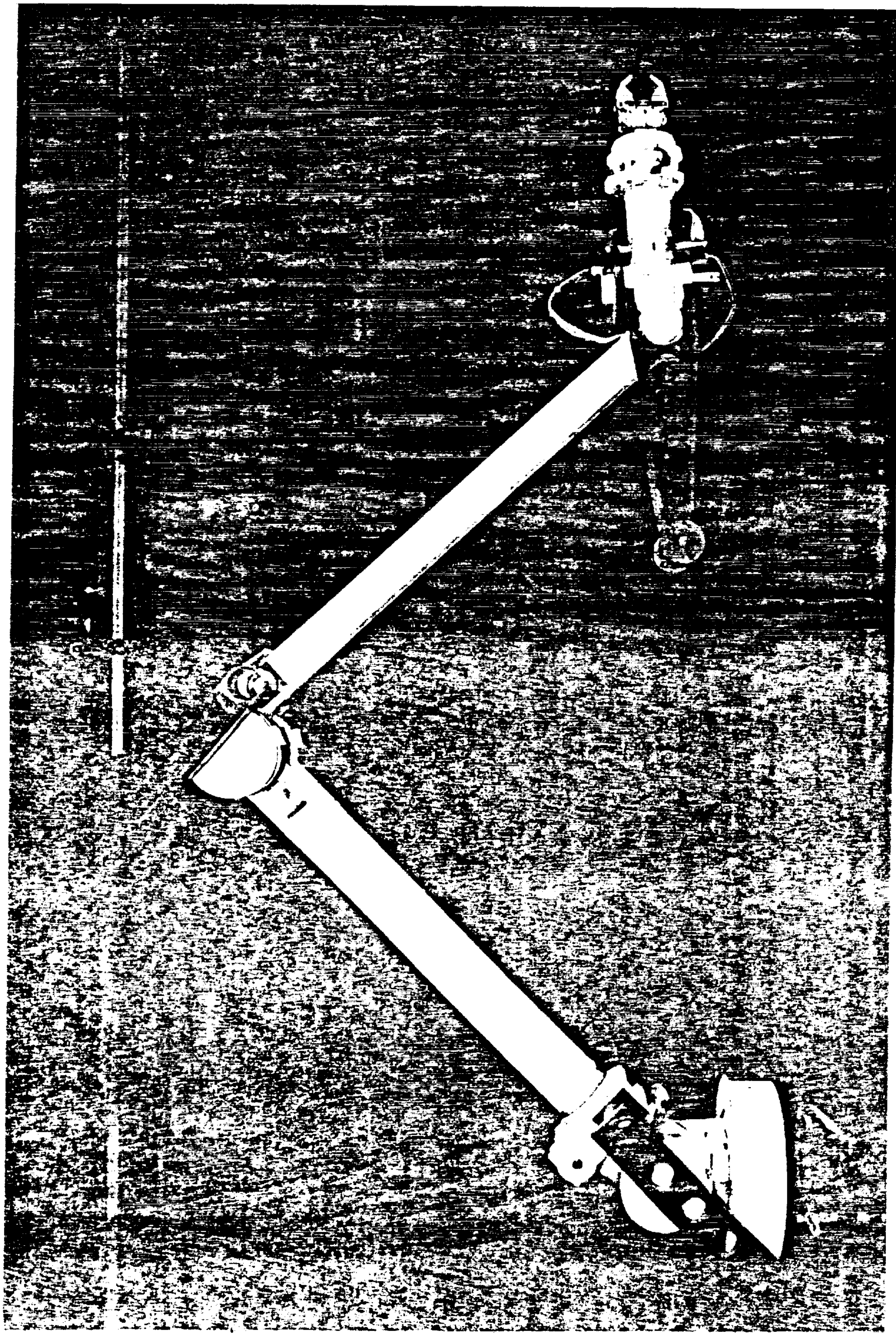


REMOTE SATELLITE SERVICING

PROTOFLIGHT MANIPULATOR ARM

The protoflight manipulator arm (PFMA), a seven-degree-of-freedom arm, was designed for such tasks as satellite servicing and space structure assembly. The PFMA has been exercised in a configuration of cameras, lighting, training task boards, interface console and digital computer.

The PFMA is an anthropomorphic manipulator assembly having flexible joints for shoulder, elbow, and wrist. The shoulder is capable of movements in the pitch and yaw axes. The elbow is capable of pitch movement, with roll/indexing capability between the shoulder and elbow. The wrist assembly provides roll, pitch, and yaw positioning for the end effector. The reach of the entire manipulator is in the range of 25 cm (10 in.) minimum to 200 cm (96 in.) maximum measured along a line from the shoulder pitch axis to the wrist pitch axis. Total arm length including wrist and end effector is 3.05 m (10 ft.). The indexing motion extends coverage to an approximate hemispherical shape over the grasping interface. Each joint consists of one or more 28 Vdc reversible motors, and movement is accomplished through a system of gears and/or clutches.



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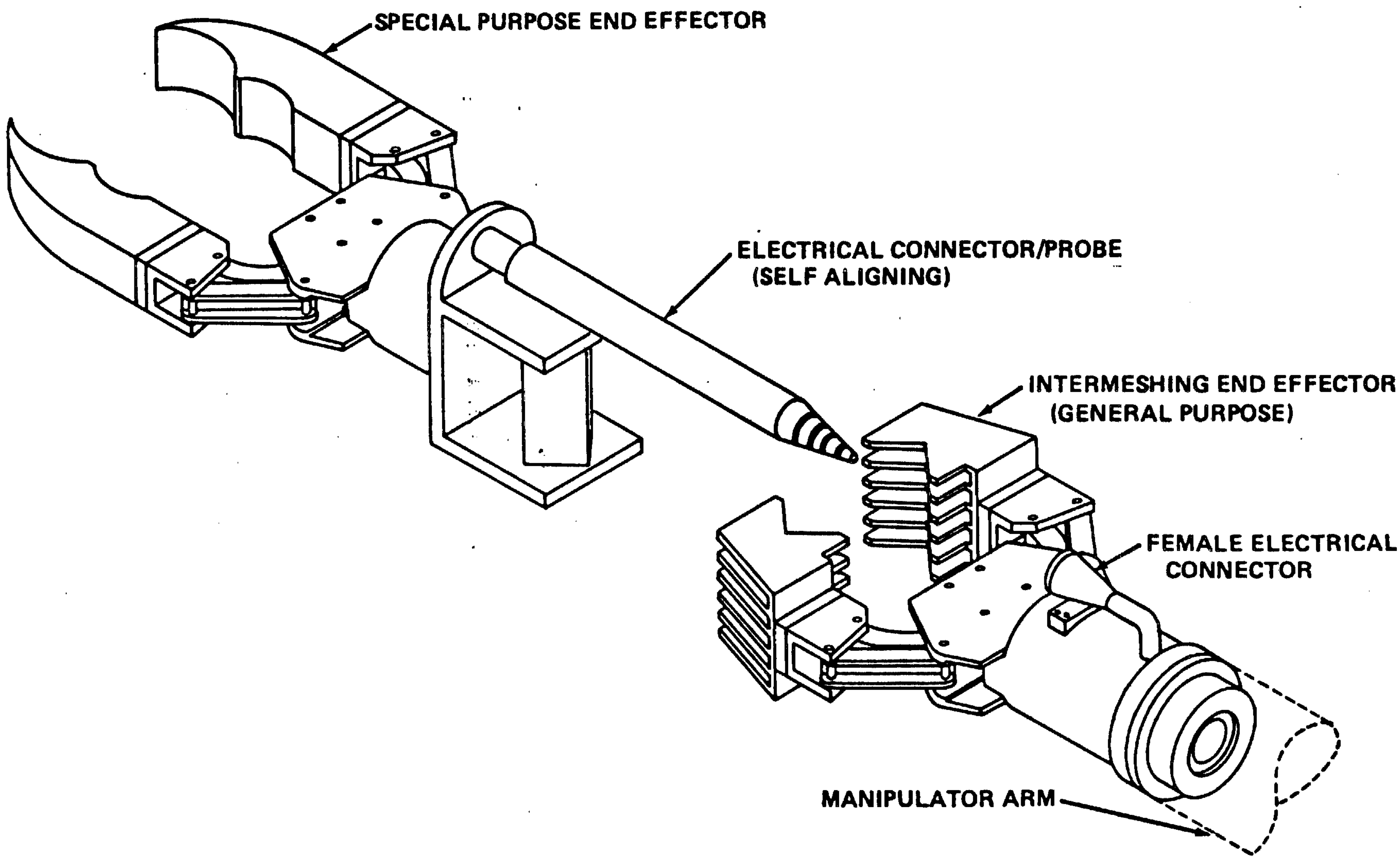
REMOTE SATELLITE SERVICING

An intermeshing end effector was developed for the PFMA and so named because its fingers intermesh with each other like a tuning condenser when the hand is closed. The hand will grasp different size and shape objects. The intermeshing end effector will be utilized to evaluate and demonstrate a set of interchangeable tools. Also, JPL is now developing a "smart" hand with force and torque sensing, adapting the intermeshing concept, that will be evaluated on the PFMA.



END EFFECTOR TOOL INTERFACE

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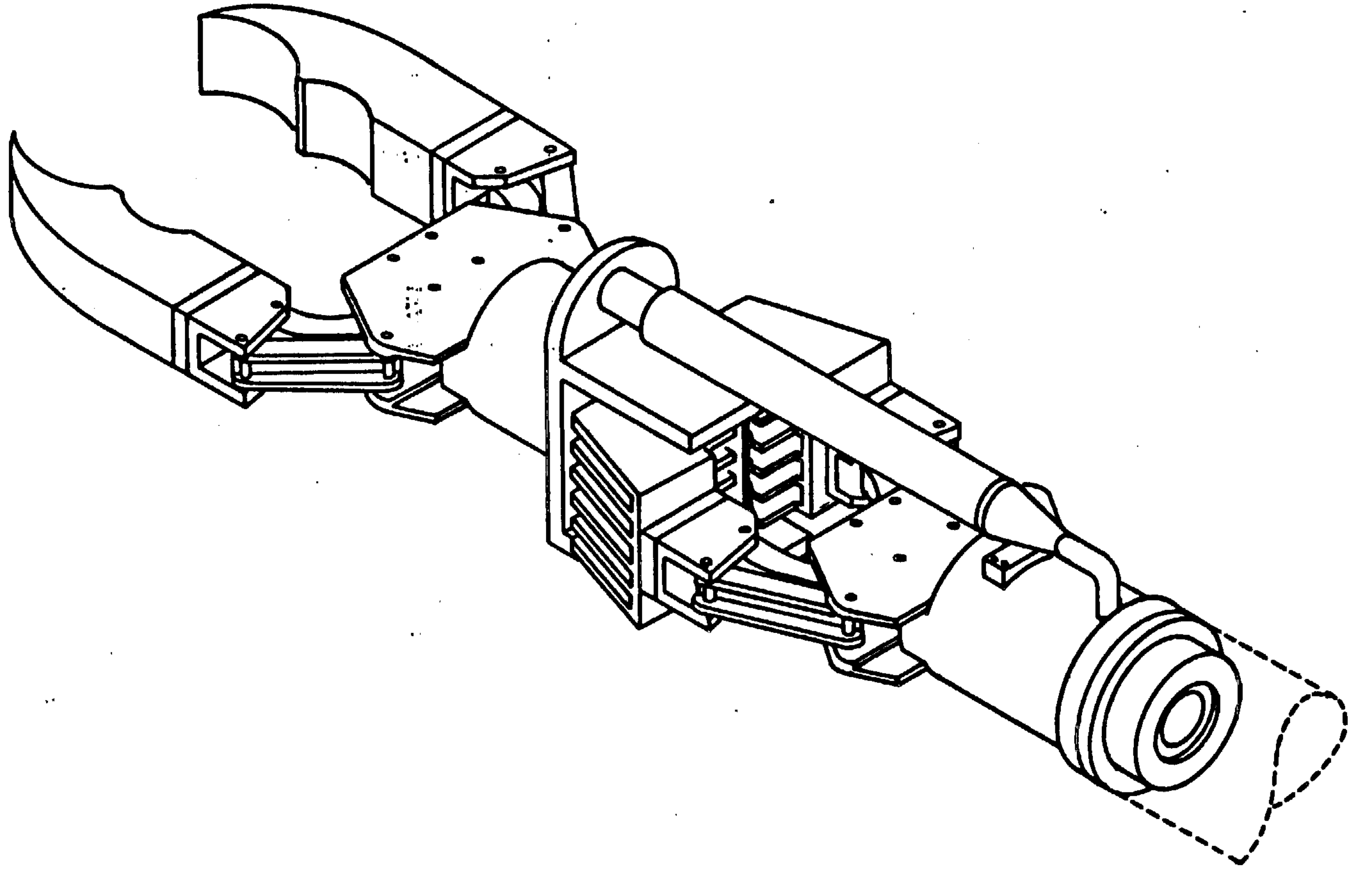
C-7

5A-107

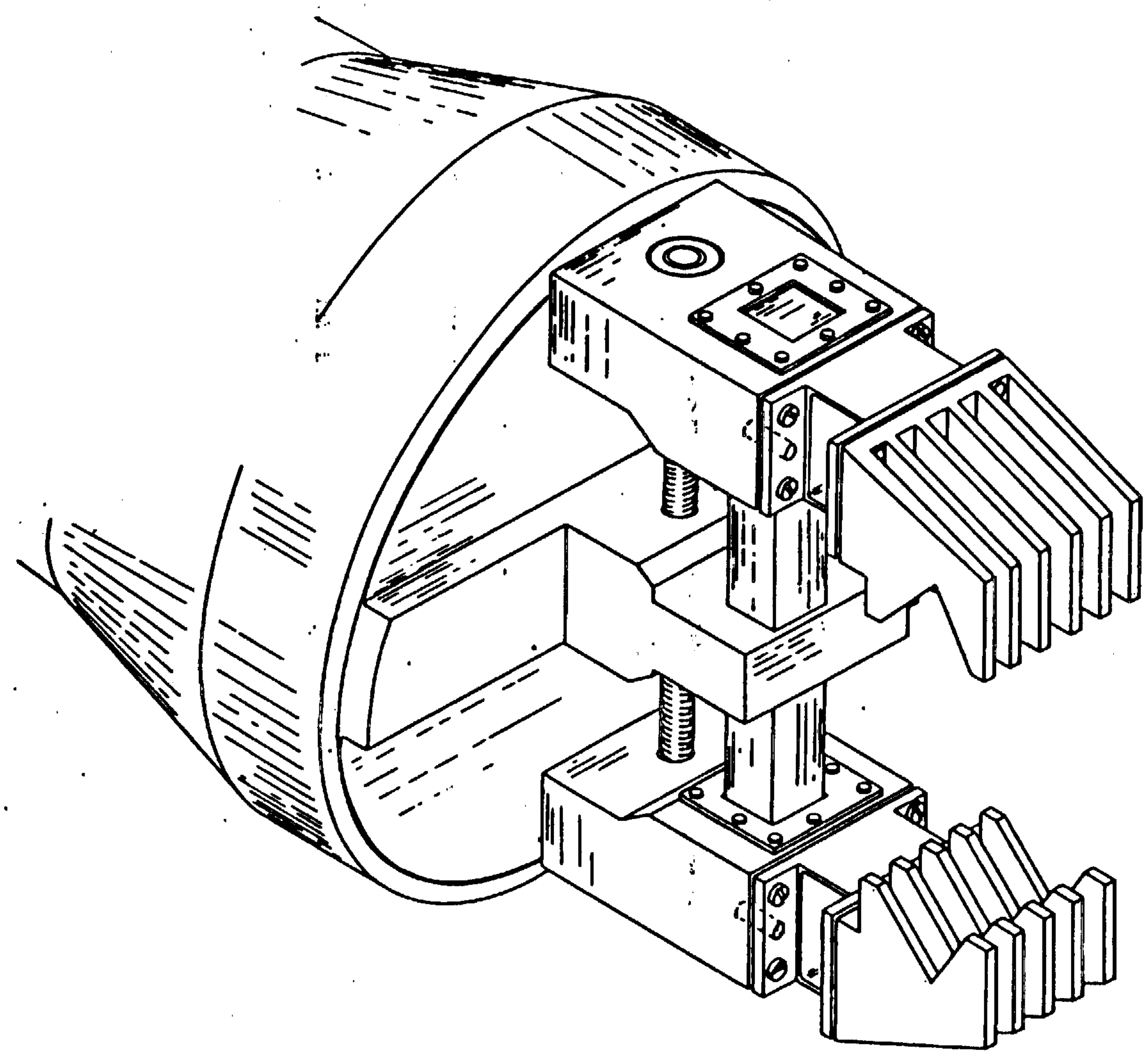


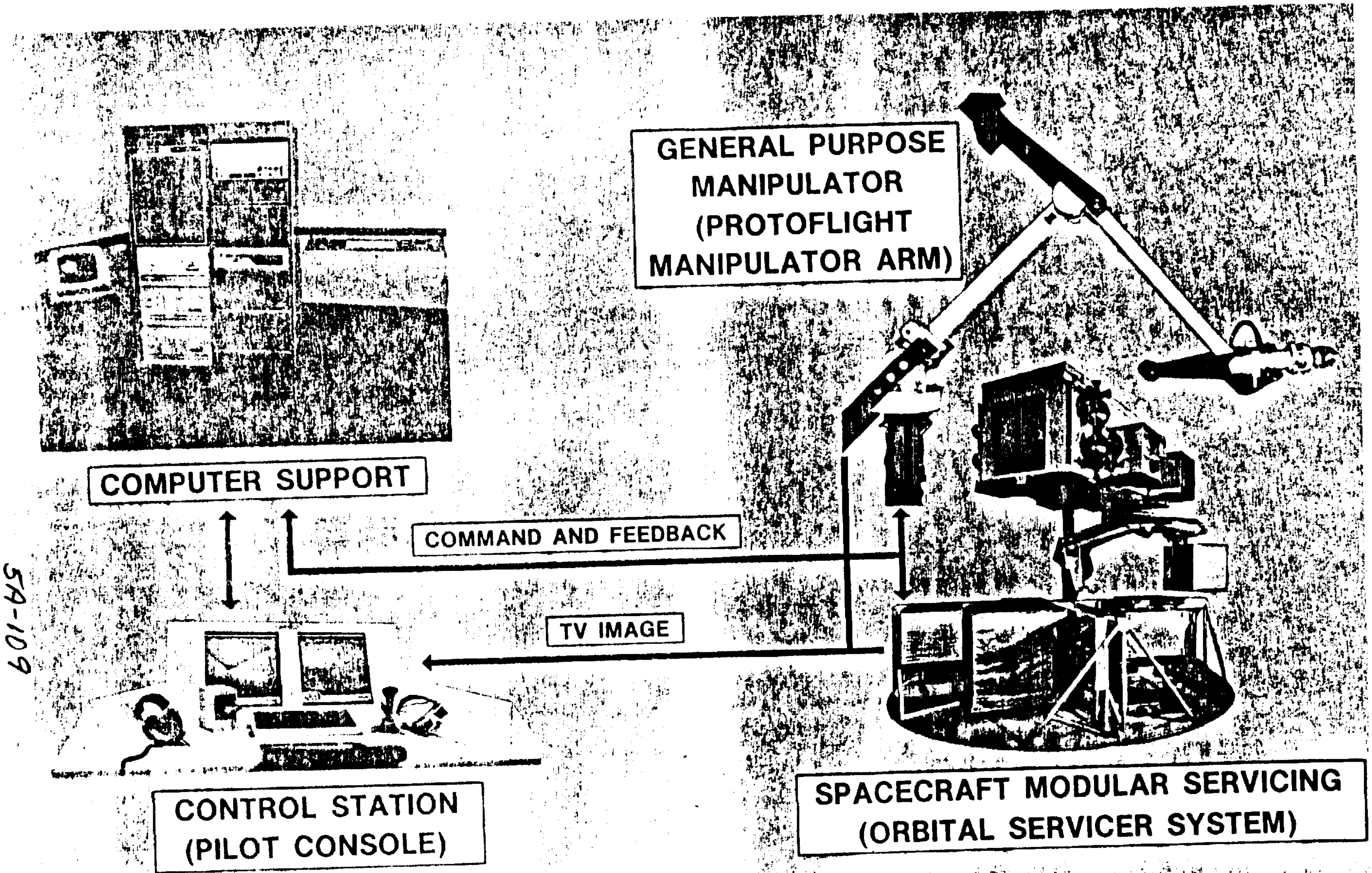
END EFFECTOR TOOL INTERFACE

JPL

OVERALL VIEW OF SERVO GRIPPER ASSEMBLY WITH FORCE AND GRASP FORCE SENSOR AND INTERMESHING CLAWS WITH ONE SQUARE SUPPORT COLUMN AND LINEAR ROLLER BEARINGS

5A-108





MSFC ROBOTICS FACILITY
(MANIPULATOR ARM)

KEY ISSUES IN REMOTE SATELLITE SERVICING

- MANIPULATOR ARM/INTERFACE MECHANISMS/END EFFECTORS
- COMMUNICATION TIME DELAY
- COMMUNICATION BANDWIDTH LIMITATIONS
- VISION RELATED ISSUES
- TARGET LIGHTING
- CONTROL COMMAND CHARACTERISTICS
- INFORMATION PRESENTATION/DISPLAY

5. Mechanisms and Man/Machine Operations

Remote Satellite Servicing

Summary:

The focus of Remote Satellite Servicing at MSFC is system oriented. The approach emphasizes ground-based experimental and simulation techniques involving autonomous as well as man-in-the-loop operations. Simulations include manipulator arms performing modular exchanges, more dexterous tasks and approach/docking operations utilizing an air-bearing 6 DOF mobility unit maneuvered on a flat floor. The total MSFC program involves a blend of system and subsystem investigations oriented toward remote operations to support teleoperation capabilities for future space missions.

Conclusion/Recommendation:

There is little doubt that remote satellite servicing is practical with present-day technology, however, there must be a degree of complexity in which servicing would not be considered feasible. The different types of mechanisms utilized in servicing are of prime importance in determining servicing capability. Technology readiness level 4 (critical function/characteristic demonstrated) which includes a prototype robotic arm has been demonstrated at MSFC and the shuttle RMS has demonstrated early capability for servicing in space.

Appropriate tasks should be determined and performed in a ground demonstration leading to a space flight experiment demonstration. Further, experimental and simulation techniques for satellite servicing should be pursued to establish the degree of complexity in which servicing is practical.

RENDEZVOUS AND PROXIMITY OPERATIONS WORKSHOP,
MECHANISMS SUBSESSION

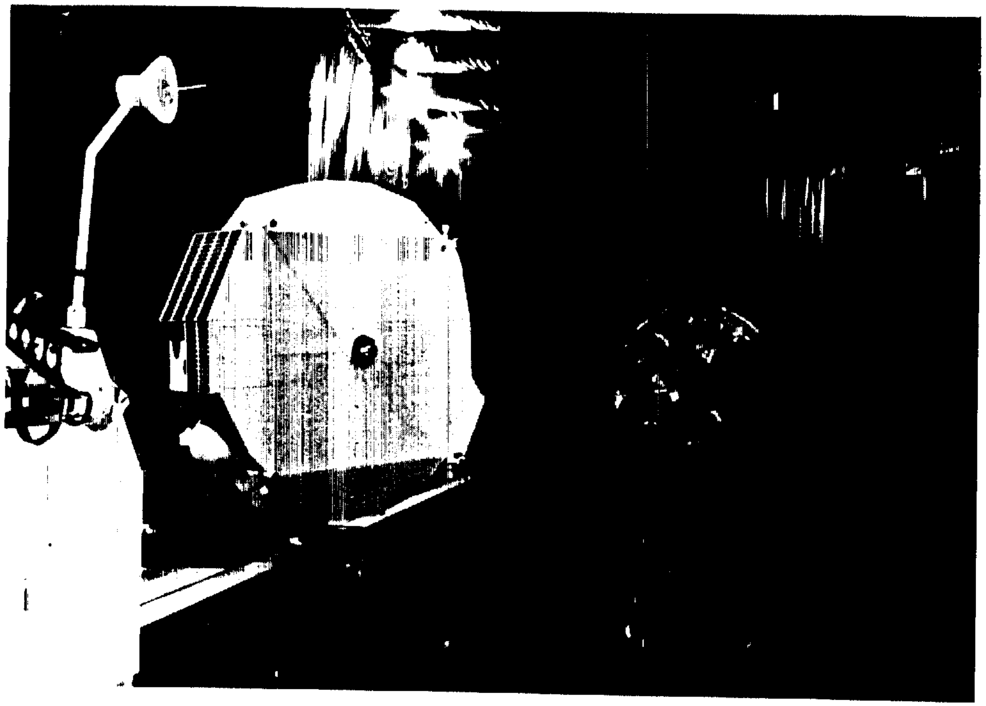
Satellite Capture Mechanisms and Simulations

Nicholas Shields, Jr.
Essex Corporation, Space Systems Group

5A-112

The Teleoperator and Robotics Evaluation Facility at the George C. Marshall Space Center is capable of supporting free-flying docking simulations of two, six degree-of-freedom space craft. Evaluations of docking concepts, ranging systems for docking, lighting of docking targets and standoff geometries and closing rates have been conducted under selected study parameters. This presentation will review the findings of several docking/capture studies and outline studies for future execution on the 4000 square foot precision air bearing floor. Comparative data will be given in terms of docking accuracy and fuel and time consumed in docking for docking mechanisms, control modes and visual feedback conditions.

5A-113



A generic OMV mockup under remote control in preparation for rendezvous with a Space Telescope aft-end mockup. Full scale OMV mockups can be exercised across the full 86 foot length of the precision epoxy floor.

Simulation Considerations

In remote rendezvous and docking exercises it is often the case that operator performance is most strongly effected by subsystem considerations such as:

1. Approach Geometries
2. Lighting Considerations
3. Types and Numbers of Cameras and Sensors
4. Hand Controller Design for Mobility Control
5. Thrust Modes
6. Vehicle Rates and Masses
7. Displays and Information Organization

Each of these parameters should be carefully controlled and understood while investigating specific engineering models of particular capture devices and docking mechanisms. This will preclude performance differences attributable to design differences among devices from becoming confounded with differences inherent in this subsystem variations.

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Simulation Facilities

Currently, the Teleoperator and Robotics Evaluation Facility provides for systomatic evaluation of a wide range of remote system components. Simulations can be conducted varying all of the following system characteristics.

1. Remote Operators Workstation
2. Hand Controllers for Flight and Docking
3. Displays of the Visual Scene and Supporting Graphics
4. Docking Mechanisms and Devices
5. Time Delay in the Command and Response Link
6. Remote Vehicle and Target Vehicle Dynamics
7. Thruster Response and Power
8. Environmental and On-Board Lighting
9. Range and Range-Rate Sensors and Displays
10. Docking Targets and Grappling Devices
11. Closing Distances, Orientations and Approach Geometry.

Docking Mechanisms

Specific docking mechanisms which have been evaluated in the TOREF and those which are currently available for testing include the following:

1. Docking/Retrievable Mechanism (DRM) - Active Extendable/Retractable male probe with active capture fingers which engage a demale docking plate.

2. RMS End Effector - Active female snare which engages a male RMS grapple fixture.

3. Three Claw Docking Device - Three point fixture with extended arms to grapple three trunnion fitings on Shuttle payloads. Claws are passive with active capture latches engaged after docking.

4. Three Fingered, Three Claw Docking Device - A three point docking device with active capture fixtures and active latches.

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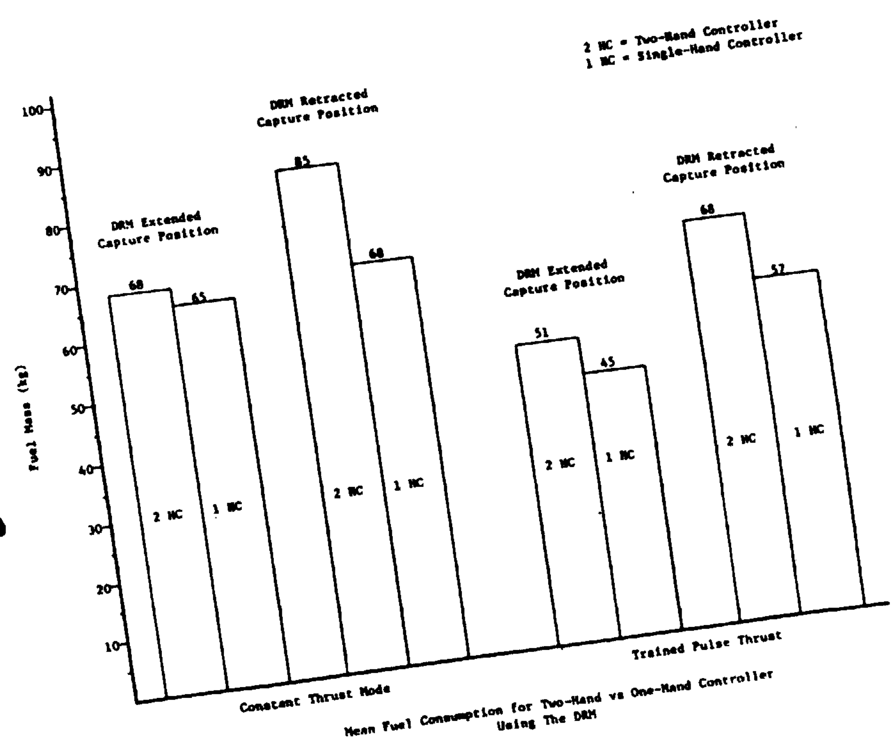
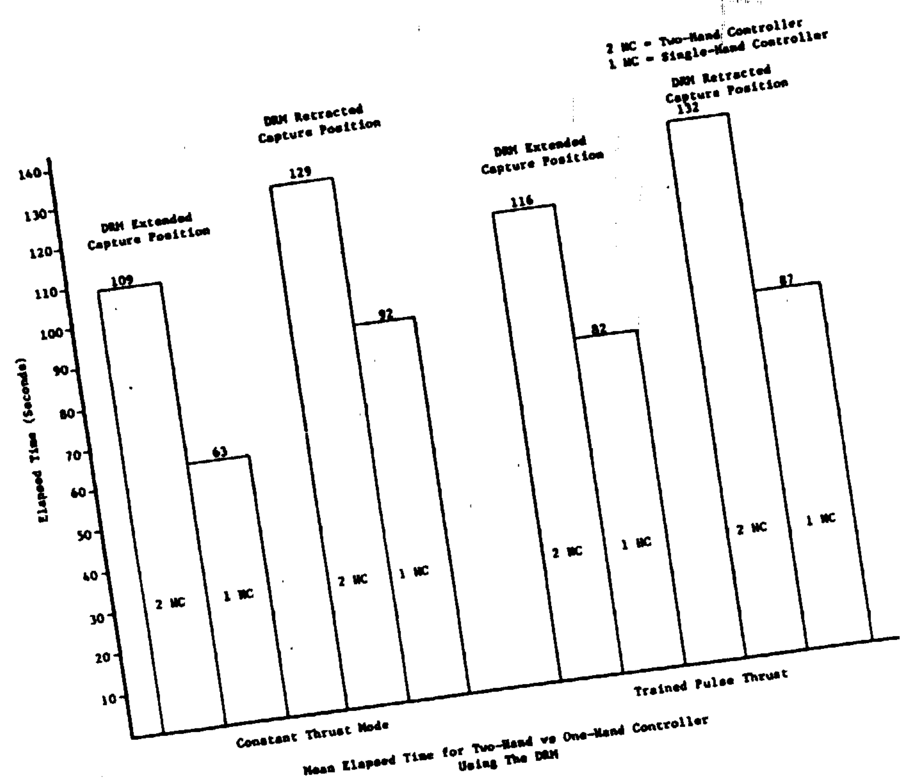
General Simulation Findings

Some general findings concerning approach and docking simulations to date are summarized below:

- Fuel consumption is reduced when the thruster firing is pulsed at fixed intervals during a command period when compared to that at constant thrust during a command.
- For terminal approach and docking maneuvers a single integrated hand controller requires less time and fuel to effect a dock than does a two joy stick control design.
- Operator control over visual display parameters such as sensitivity, focus, iris, and contrast appears to be necessary to compensate for the severity of environmental illumination.
- Some small advantage is exhibited for bore sighted cameras vs. offset/target aligned cameras during docking maneuvers.





Fuel and Time Consumed During Docking Maneuvers. Data Show a Consistent Advantage for Single Integrated Hand Controllers.

Future Docking Mechanism Simulation Requirements

The requirements for future missions have revealed the following areas of investigation which will be addressed during the next year.

- Comparative docking success with an active capture/latch mechanism. This will be the MSFC design employing the three fingered capture device.
- Post docking manipulation using dedicated manipulator controllers vs. the flight controllers.
- Docking target design and configuration.
- Requirements of payload variations such as Space Telescope, Multi-Mission Modular Spacecraft, Space Structures Berthing Ports, etc.
- Integration of docking studies and simulations with orbital servicing and orbital construction requirements.

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Conclusions

- The Teleoperator and Robotics Evaluation Facility at MSFC offers an integrated simulation facility in which system level investigations can be carried out using full scale, six degree-of-freedom spacecraft mockups under remote operator control.

- The carefully controlled environmental conditions in the laboratory provide a bias free test environment.

- Docking studies conducted in this and other mobility laboratories at MSFC tend to support the proposition that subsystem and component designs exert very strong influences on docking performance. The cumulative effects of these may be more significant than any particular device design.